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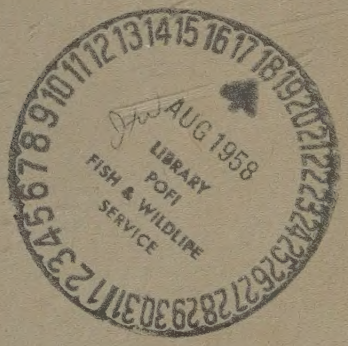

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FOREWORD

The oceanographic projects of this Commission were started in 1953 with the participation of many distinguished marine scientists of Japan. Some of the results obtained in 1955 were published last year in the Special Number of the "Records of Oceanographic Works in Japan", a pre-war scientific journal, which was revived in 1953 by the Commission.

The present issue which constitutes the second special number of the said journal contains reports on the above-mentioned oceanographic projects conducted during 1956.

It is hoped that together with the previous issue this number will be of use to all those concerned with marine sciences abroad.

March 1958

Japanese National Commission
for Unesco

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A STUDY ON THE PRODUCTIVITY OF THE TANABE BAY (PART I)*

By Denzaburo Miyadi** and Shoitiro Hayami***

Introduction

For the estimation of biological productivity of the sea, a number of knowledges from physical, chemical, geological and biological aspects are required. Among them are physical and chemical properties of sea water, including the contents of nutrient salts and organic substances in the sea water as well as the conditions in which these substances become available for plants and animals; dynamics of sea water; regional characteristics of geological and topographic properties; the constitution, standing crop and seasonal cycle of plankton, benthos and nekton; reproduction habits, growth and seasonal activity of useful animals; and the food chain and the efficiency of energy exchange among different food levels.

In the case, where the productivity of a definite area of the sea is to be studied synthetically, however, it is essential to have the data, for examples, on the exchange of nutrient substances between the area and the surrounding areas due to influents as well as the horizontal and vertical mixing caused by tidal and other currents; and the heterogeneity of physical factors within the area and the way of their relation to the biological production.

As to the Tanabe Bay, its fauna and flora have been made clear by the effort for more than thirty years of the Seto Marine Biological Laboratory, and in more recent years, such data as the seasonal changes of nutrient salts, plankton and benthos, the so-called multiplication area of plankton with reference to its marine conditions have been accumulated together with the general features of littoral communities and shore fishes. The Oceanographic Laboratory of the Kyoto University, on the other hand, has been concerned with the dynamics of sea water, and it has elaborated a new method for the estimation of the exchange of water

* The authors are indebted to the Japanese National Commission for Unesco for the aid to this study.
Contributions from the Seto Marine Biological Laboratory, No. 305.
** The Seto Marine Biological Laboratory, Kyoto University.
*** The Geophysical Institute, Science Department, Kyoto University.

between different water masses by measuring the difference between the actual density and the calculated density from Knudsen's table on the basis of chlorinity.

The present survey of the Tanabe Bay in 1956 is the first cooperative work of these two organizations with the aid of Prof. A. Nakamura of Osaka University of Liberal Arts and Education to get a synthetic idea on the capacity of the Tanabe Bay as a production system. It is, however, far from achieving the object of the study, because of the lack of several important knowledges. For an example, we still have no data on the standing crop of larger invertebrate animals and fishes to form the pyramid of biomasses. So far we have succeeded in getting such elementary data as hitherto have been unknown to us. They are:

1) the exchange of the surface water across the two sections, one near the mouth and the other in an inner part of the bay;

2) the current velocity in the strata between 0 and 6m in depth;

3) the distribution of water temperature, water color, transparency, salinity, Si and P contents, and the catalytic activity of sea water;

4) the distribution of plankton with reference to the mixing of sea water by tidal and other currents;

5) some rules on the distribution of coastal fishes with reference to their size and quantity; and

6) the distribution of benthic animals in the tidal zone with their ecology.

The details on each subject will be dealt with by the respective author.

It is however important for the synthetic study on the production system to have the data on the movement of sea water in vertical sections as well as in the surface layer. It is also essential to make efforts of bringing the knowledges more interdependently and establish a method to determine the quantitative relations among plankton, benthos and nekton. Some of these efforts will be realized in the report for 1957.

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A STUDY ON THE PRODUCTIVITY OF THE TANABE BAY
(Part I)

I. Oceanographic Conditions of the Tanabe Bay
Results of the Survey in the Autumn of 1956

By Shin-ichiro Fuse, Isamu Yamazi and Eiji Harada
(Seto Marine Biological Laboratory, Kyoto University)

Introduction

In order to elucidate the basic structure of marine bio-productivity in the Tanabe Bay, the writers have undertaken oceanographic observations in Tanabe Bay. In this report, the results of physical and chemical analysis of the environment are briefly described to make some contributions to this problem.

The Tanabe Bay is located on the southwest coast of the Kii Peninsula with its centre approximately at Lat. 33°42.5'N and Long. 135°22'E. The mouth of the bay opens to west and the area is separated from the Pacific Ocean by three rocky reefs (Nada-sima, Okino-sima and Naka-sima) and two promontories (Mori-saki and Bansyo-no-hana). The greatest depth is about 34 meters near the mouth. The shore line is mainly rocky on the south-east coasts and sandy beaches are developed on the northeast.

During 9th-11th of November, 1956, water sampling, measurements of transparency and water colour, and three hauls of plankton net were made at each of 100 stations in the bay. Fig. 1 shows the map of the Tanabe Bay and locations of stations.

At each station, water samples of all respective layers were collected at time intervals as short as possible, with three Nansen's bottles (at 15 and 20[1)] meters below the surface and bottom layer), two Kitahara's insulated bottles (at 5 and 10[2)] meters below the surface) and canvas bucket (at surface). Using these samples, water temperature was measured (especially at three layers above the bottom, a reversing thermo-

1) 2) 10 and 20 meters layers were sampled at 10 stations which lie on a line observed during a survey on the mixing of water mass.

meter was used with the Nansen's bottles) and in the laboratory after the field work, chemical treatments were made.

Chlorinities were determined by a modification of Knudsen's method, 5 cc of sea water which was diluted by adding about 50 cc of pure water were titrated, using Japanese standard sea water to standardize the silver nitrate. The Atkins-Denigo's method was used for inorganic phosphates and Diénert-Wandenbulcke's method for inorganic silicate. The colours, which are 730mμfor P and 420 mμfor Si, were measured by the type "EPV-2" of Hitachi Photo-Electric Spectrophotometer.

During the survey, it was usually cloudy, but rainy on 10th (precipitation 33.7 mm), air temperature ranging from 22.3°C to 15.1°C. Beaufort's wind scale, Douglass' well scale and sea wave scale are in a range of 0~2 respectively.

Descriptions of the Hydrological Conditions

1. *Water colour* (Fig. 2)

Colour varied from Forel's no. 8 (in Utino-ura and Mori arm) to no. 3 (in the centre of the bay and open sea). The same coloured lines nearly coincided with isobath lines, generally showing a tendency to become larger landward. Having these tendencies, Forel's values in the innermost parts and arms of the bay were greater than those in the middle region, even if at the same depth. The bluish water (Forel's no. 3) that seems to be typical of the open sea, entered in the bay from the centre of the mouth and reached the Hatake-zima~Ka-sima line.

2. *Transparency* (Fig. 3)

Transparency measured by Secchi disc reading was minimum at Mori and Hosono arms, about 2 m, and its distribution resembled that of water colour. Distribution area of 15 m transparency was nearly the same as that of colour that indicated the open sea character.

3. *Temperature* (Figs. 4-7)

Water temperature varied from 20.38°C (St. 9, surface) to 23.14°C (St. 98, surface). Temperatures on the surface layer were more variable than on the other layers. Differences on the surface were 2.76°C, on both the 5 and 15 meter layers were 1.15°C, and on the bottom were 1.83°C. Tracing the isothermal lines, it is recognizable that in general temperatures were lower from the entrance towards the inner parts and warmer waters in the mouth entered towards the southeast through the central part and reached the Hatake-zima~Ka-sima line. The lowest temperature was shown at the surface of southern two arms Kogaura and Tunasirazu. This may be due to that these stations are near the coast and observations were made about 8:00 a.m., when low temperature during the night still

remained. As to the vertical distribution, surface temperature was generally higher than bottom and its average range for all stations was 0.4°C.

4. *Chlorinity* (Figs. 8-11)

The highest chlorinity measured at the surface was 18.96‰ (St. 94) and the lowest 14.35 ‰ (St. 35). Isohaline lines ran almost parallel with the isobath lines except for the bottom layer. Distribution of the offing waters was nearly the same as the results inferred from the distribution of water temperature, transparency and water colour. Namely, open sea water entered the bay in the form of wedge and reached the Hatake-zima~Ka-sima line. In the innermost arms and estuaries of the rivers Aizu-gawa and Haya-gawa, discharge of fresh water seemed to have any appreciable effect upon chlorinity of the bay water, showing the low chlorinity less than 18.0 ‰. In Mori arm, its effect was most remarkable, but seemed to be confined only to the surface water. Vertical ranges of chlorinity were small, the maximum value being 4.42 ‰ (Mori arm), minimum 0.00 ‰ (St. 49)and mean 0.3 ‰. And it was less than 0.1 ‰ in most of the stations within the bay except at the innermost.

5. *Silicates* (Figs. 12-14)

The distribution of silicate is slightly different from that of the preceding four factors. In general, concentration of inorganic silicate found in the inner region was higher than in the outer, with decreasing tendency towards the open sea. It showed a tendency becoming lower from surface to bottom, nevertheless it is a small vertical range. Higher concentration was found in the five arms and in the northwest area where the river water pours into the bay. Especially, at the surface, silicate found in the estuary of Haya-gawa was 980γ/*L*, in Mori arm 1040γ/*L*, and in Kogaura arm 1290 γ/*L* These facts prove the great effect of fresh water pouring into the bay and coincide well with the distribution figure of surface chlorinity. Though the effect is limited only to the surface water. At St. 92, 94 and 87 lying in the outer region silicate at the surface was only traceable.

6. *Phosphates* (Figs. 15-16)

Inorganic phosphate was only traceable in all layers at almost all stations in the outer region of the bay, but within the bay in only layers deeper than 15 meters except in arms and along the northern coast where river waters pour into the bay. Phosphates were distributed in patches, here and there in the bay. In general, it had a tendency that concentration becomes lower towards the outer region from the innermost and towards the bottom from the surface. Higher concentrations of phosphates were found on the surface at Mori arm (St. 35:48.7γ/*L*), Utinoura (Sts. 25, 26 and 27: about 25γ/*L*), Kogaura (St. 9:25γ/*L*),

estuary of Aizu-gawa (St. 68:15γ/L) and Hosono (St. 15:15γ/r). These facts that relatively higher values were found at the inner parts, resembled the cases of silicates and lower chlorinity.

Vertical Stability of Bay Water Mass

As described above, the vertical range of water temperature and chlorinity in the bay was small, except in the innermost of arms. When σt calcurated, the change of σ_t in a vertical direction is indicated as nearly proportional to the vertical stability of the system, since negative value of $d\sigma_t/dZ$ [1] indicates instability while positive value indicate stability (Fig. 1). In the middle region of the bay, $d\sigma_t/dZ$ were negative or irregular, so that the water masses may be instable in the vertical direction. On the other hand, on the coastal or arm parts $d\sigma_t/dZ$ were positive and thus water masses were stable. Stable parts were shown at the 4 stations out of the bay, but it is still not clear for the present whether these stable condition extends more towards the offing. Instable parts extend from the entrance to the Hatake-zima~Ka-sima line through the center.

In conclusion, it is assumed that the movement of water mass is very complex in the mouth and center of the bay, on account of upwelling caused by reefs or vertical circulation caused by seasonal lower surface temperature.

Fig. 1. Chart of Tanabe Bay. Number shows location of hydrographic stations.

Heavy and vertical number indicate station where $d\sigma_t/dZ$ is positive at every layer. Heavy and oblique number indicate station where on the other hand light and oblique station $d\sigma_t/dZ$ is negative or irregular at all layers, $d\sigma_t/dZ$ is negative at only one layer.

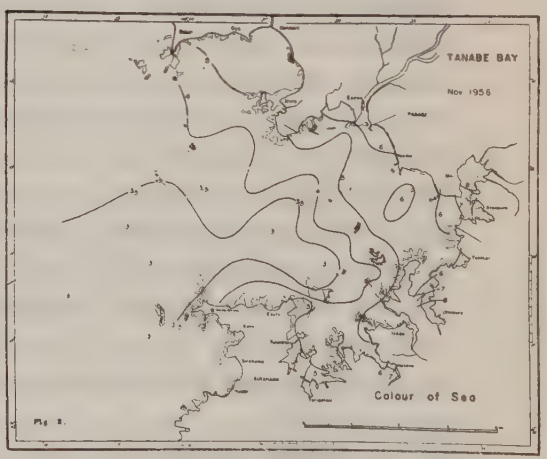

Fig. 2. Horizontal distribution of water colour in Forel's no.

1) Z is the depth.

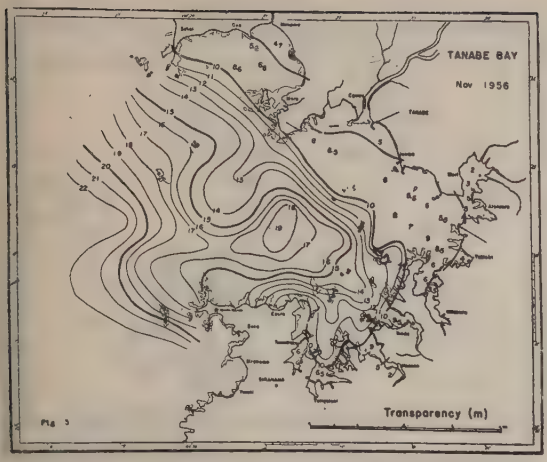

Fig. 3. Horizontal distribution of Transparency by Secchi's disc reading in meter.

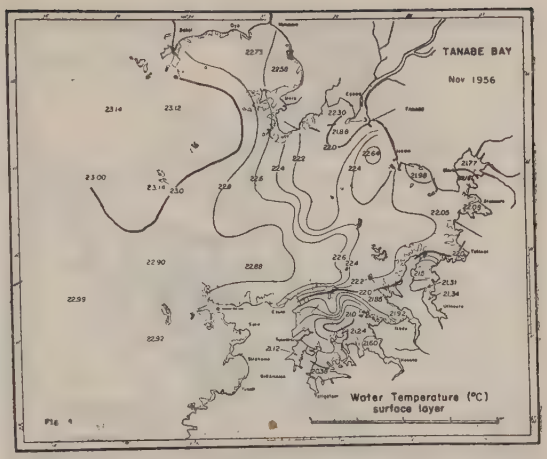

Fig. 4. Water temperature (°C) at the surface.

Fig. 5. Water temperature (°C) at the 5 m below the surface.

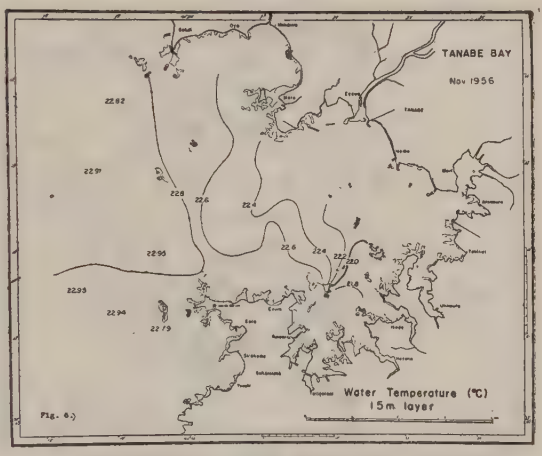

Fig. 6. Water temperature (°C) at the 15 m below the surface.

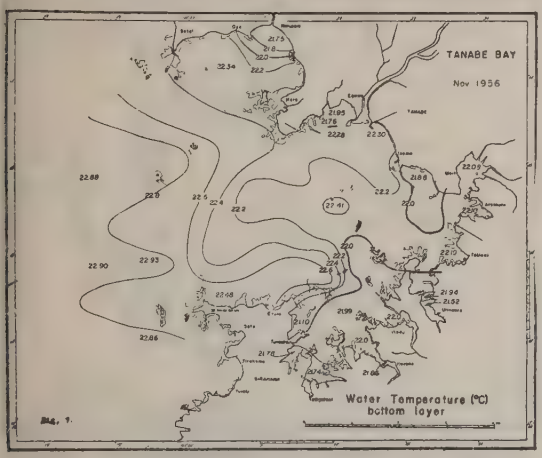

Fig. 7. Water temperature (°C) at the Bottom.

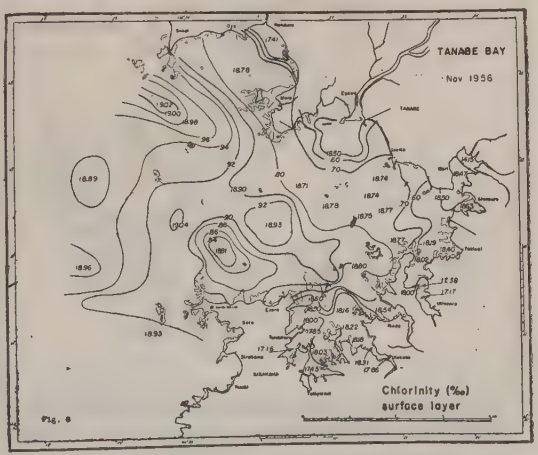

Fig. 8. Chlorinity (‰) at the surface.

Fig. 9. Chlorinity (‰) at the 5 m below the surface.

Fig. 10. Chlorinity (‰) at the 15 m below the surface.

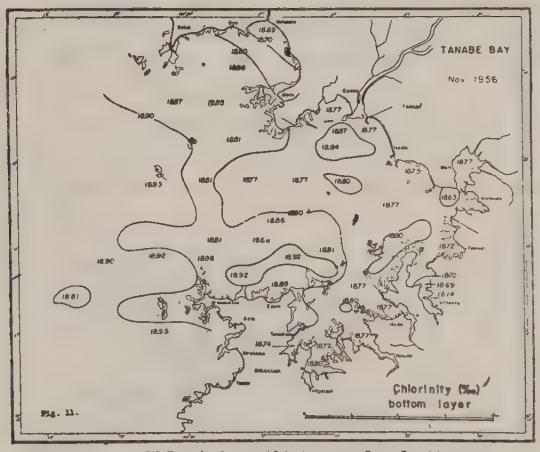

Fig. 11. Chlorinity (‰) at the bottom.

Fig. 12. Horizontal distribution of silicat (in γ per liter of SiO_2) at the surface.

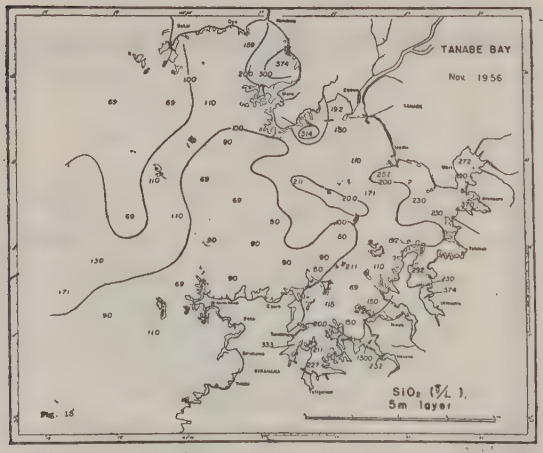

Fig. 13. Horizontal distribution of silicate (in γ per liter of SiO_2) at the 5 m below the surface.

Fig. 14. Horizontal distribution of silicat (in γ per liter of SiO_2) at the bottom.

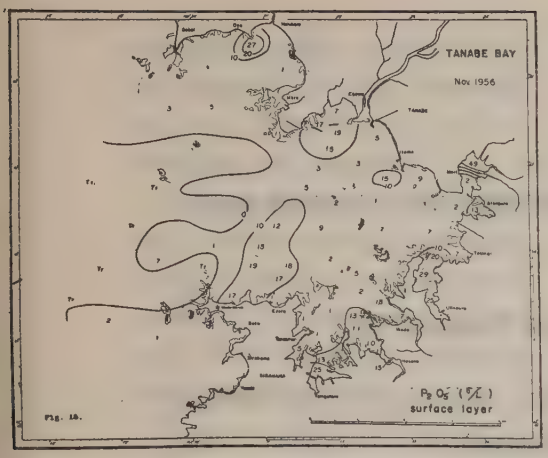

Fig. 15. Horizontal distribution of phosphate (in γ per liter of P_2O_5) at the surface.

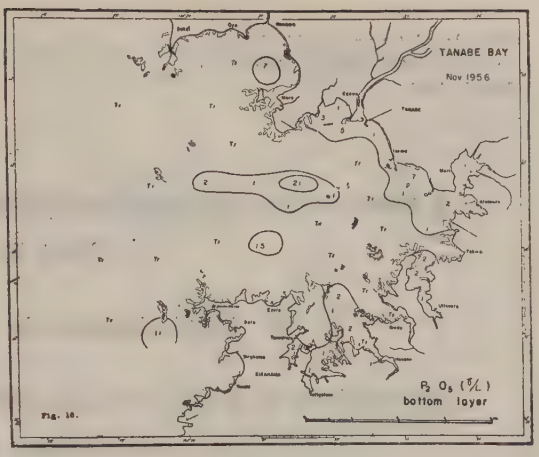

Fig. 16. Horizontal distribtuion of phosphate (in γ per liter of P_2O_5) at the bottom.

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A STUDY ON THE PRODUCTIVITY OF THE TANABE BAY
(Part I)

II. Tidal Currents in the Tanabe Bay

Observations of Tidal Currents by the Method of Drift Bottles
(Introductory Report)

By Akikazu Nakamura
(Osaka University of Liberal Arts and Education)

I. PERIOD OF OBSERVATION. From 3rd to 10th, November, 1956.

II. METHOD OF OBSERVATION. As the first step, "drift bottles" were used for obtaining informations on the tidal currents in the Tanabe Bay, where it seemed inadequate to use the current meters on account of slow flow.

The author adopted two kinds of bottles, the one kind named "ordinary bottles" were weighted with sand or water so that they were slightly visible from the surface (we call them O), the other kind named "special bottles" consisted of pair bottles, one of each pair was so weighted as to be carried by the other, the connecting wire between the pair bottles was respectively 0.5, 1.0, 1.5, 3.0, 6.0 meters long (we call them 0.5, 1.0, 1.5, 3.0, 6.0).

As a rule, we released ten of 0, five of 0.5, 1.0 and 1.5 respectively, three of 3.0, and two of 6.0 at each station, and

Fig. 1. Map showing the stations. Asterisks within circles show the places of tide-gauges.

recovered them from a ship at intervals of about half an hour or longer according to velocities of currents.

The positions of release and recovery were determined by a sextant, and the estimates of average velocities and directions of currents were made.

Occasionally, the cup-type current meter was used and the results showed fairly good accordance with those of bottles.

The wind was also measured at about 1 meter above the sea surface at the places of release and finding of bottles, or at opportune times.

The tides were observed at two points, i.e., Mori at the head of the bay and Seto near the opening of the bay, by Prof. S. Hayami. The author was allowed to use the complete marigrams during observations.

III. RESULTS OF OBSERVATION. As is shown in fig. 1, observations were made at 30 stations, but the data obtained were not satisfactory for obtaining the general information on the currents of the surface layer of this bay. So, this paper deals only with the observed motions of bottles, which are classified into the following seven cases with reference to

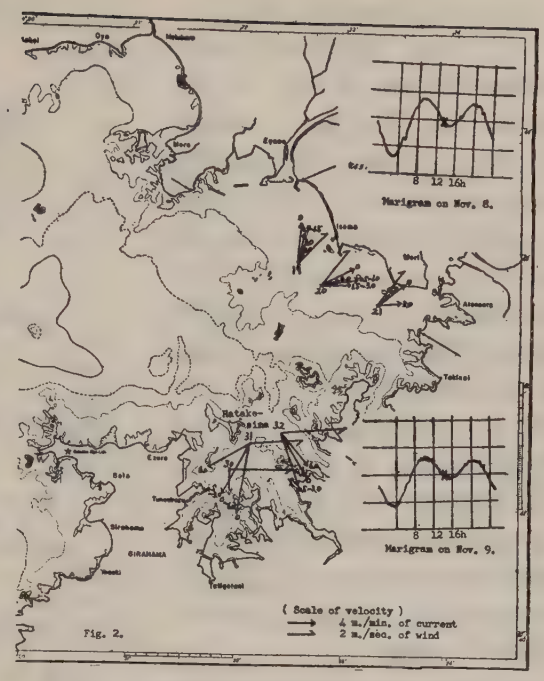

Fig. 2. Current velocities at stations 19, 20 and 21 at the tidal phase of the X mark on the marigram taken at Mori on Nov. 8; and at stations 30, 31 and 32 on Nov. 9.

Fig. 3. Current velocities at stations 9 and 10 at the tidal phase of the X mark on the marigram taken at Mori on Nov. 5.

the tidal phases at Mori.

1. Near the low water. (Nos. 19, 20, 21, 30, 31 and 32 in Fig. 2) As is shown in Fig. 2, in the northeastern area of the bay, there occur northerly flow at No. 19, and easterly or northeasterly flow at Nos. 20 and 21. In all stations, velocities are 4～5 m/min 1～2 m/min for 6.0. In the area for 0, 2～3 m/min for 3,0, and to the south of Hatake-sima, the current runs southeasterly and then turns to the southwest at velocities of 6～9 m/min against the westerly wind of about 4 m/sec.

2. The middle phase between low and high tides. (Nos. 9 and 10 in Fig. 3) As is shown in Fig. 3, at the opening of the bay, the currents run to the southeast at 2～6 m/min but the bottle of 3.0 at No. 9 shows an extraordinarily rapid flow (10.9 m/min to the east. On the contrary, both 1.0 and 1.5 at No. 10 flow slowly (1.4 m/min) to the east. It is noticed that the layer between the depths of 1 and 3 meters shows different flow from other layers.

3. From the middle to the high water. (Nos. 34 and 37 in Fig. 4) Fig. 4 shows that there exist flows of about 3 m/min to the east or east by north at about the center on the line across the mouth of

Fig. 4. Current velocities at stations 34 and 37 at the tidal phase of the X mark on the marigram taken at Mori on Nov. 10.

Fig. 5. Current velocities at stations 22, 23, 24, 25, 26, 27 and 28 at the tidal phase of the X mark on the marigram taken at Mori on Nov. 9.

the bay (No. 34), while the outflow (3~5 m/min) is observed at No. 37.

4. The high water and its vicinities.

a) Before and at the high water. (Nos. 22, 23, 24, 25, 26, 27 and 28 in Fig. 5) As is shown in Fig. 5, there are various currents at the opening of the bay; i.e., slow currents entering into the bay in the central region (Nos. 23, 24 and 27) ; no motion except the southerly flow of 1.5 and 0 at No. 26; rather strong flow to the south by east (above 3 m/min) at No. 28; and weak outflows at Nos. 22 and 25.

b) After the high water. (Nos. 14, 15, 16 and 17 in Fig. 6) As is shown in Fig. 6, the currents at the opening are quite different from those in a). In the central region, there exist an outflow of over 2 m/min at No. 17, although No. 15 shows the flow to the south at 3 m/min Nos. 14 and 16 show outflows to the southwest and the north respectively. It should be noted that even the small change of tidal phase causes such different current as in this case.

5. From the high water to the middle. Nos. 11, 12 and 13 in Fig. 7) Fig. 7 shows that there are southwestern currents of 3~6 m/min in the southern area of the bay, and

Fig. 6. Current velocities at stations 14, 15, 16 and 17 at the tidal phase of the X mark on the marigram taken at Mori on Nov. 8.

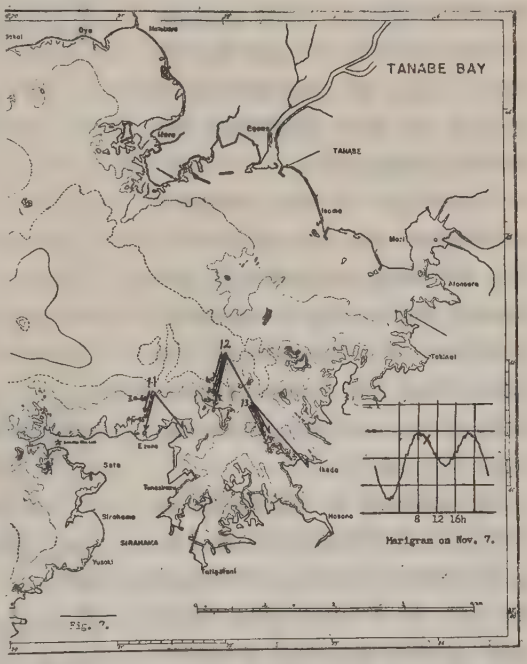

Fig 7. Current velocities at stations 21, 12 and 13 at the tidal phase of the X mark on the marigram taken at Mori on Nov. 7.

southeasterly flow (3~5 m/min in the area to the east of Hatake-sima.

6. The middle between the high and low tides. (Nos. 5, 6, 7 and 18 in Fig. 8) In the northern area, as is shown in Fig. 8, there are northeasterly current at No. 7, northwest current at both stations of Nos. 6 and 18, and very strong outflow of above 10 m/min at No. 5.

7. From the middle to the low water. (Nos. 3 and 4 in Fig. 9) The surface water near Kinugasa (No. 4) flows rapidly to the southeast at 7~10 m/min) on account of the strongest wind (about 7 m/sec that ever experienced during our observations. Slow easterly flows of 1.5, 3.0 and 6.0 at No. 3 may be considered to be due to the influence by bottom topography.

According to the present experiment by the drift-bottles, the tidal currents in the Tanabe Bay seem so complicated to be interpreted in short, that we have to continue more accurate observations frequently.

The author is indebted to Prof. Dr. D. Miyadi, Prof. Dr. S. Hayami, Dr. H. Utinomi and Dr. I. Yamazi for their kind guidances and encouragements in these investigations.

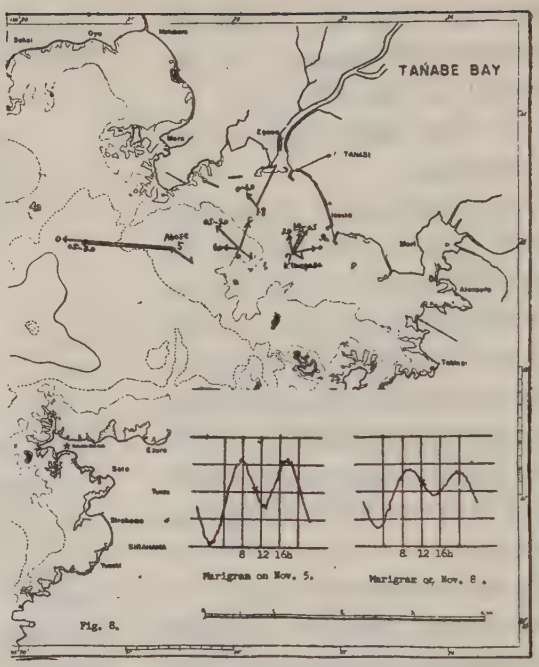

Fig. 8. Current velocities at stations 5, 6 and 7 at the tidal phase of the X mark on the marigram taken at Mori on Nov. 5, and at station 18 on Nov. 8.

Fig. 9. Current velocities at stations 3 and 3 at the tidal phase of the X mark on the marigram taken at Mori on Nov. 4.

Records of Oceanographic Works
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March 1958

A STUDY ON THE PRODUCTIVITY OF THE TANABE BAY

(Part I)

III. On the Exchange of Water and the Productivity of a Bay with Special Reference to the Tanabe Bay

By Shōitirō Hayami, Yoshiaki Fukuo and Daisuke Yoda
(Geophysical Institute, Kyoto University)

1. Introduction

As the life of living beings is maintained by the complex of organic compounds, the biological productivity of the sea may be defined by the productivity of organic compounds in the living beings in the sea. In this respects, the production of organic compounds by the photosynthesis in phytoplanktons or the small suspensoids of organic origin in the sea may be used as an indicator of the productivity and, in fact, basing on these indicators many researches of the productivity were made so far. In such a treatment the sea water acts only as a carrier of planktons or suspensoids and the relation between the productivity and the sea water does not appear in the foreground. Planktons and suspensoids do not uniformly disperse in the sea water and their origin is not necessarily clear, so it will not be an easy task to determine their total quantity, distribution and fluctuation in any sea region, and many practical difficulties are expected in the quantitative representation of the productivity by them. Another approach to the estimation of the productivity is to determine the amount of carbon, nitrogen, phosphorus, oxygen and so on in the sea water which are necessary for the production of organic compounds and many comprehensive researches were also made along this line. As these elements are a part of the constituents of the sea water, their quantitative estimation is relatively simple and the budget of these elements in a limited sea region offers a useful knowledge of the productivity in the region. This method may be called as the chemical representation of the productivity in contrast to the biological one. It is, however, difficult to estimate the amount of the production of living beings from these elements, because they only contribute in part to the formation of a living body.

The transmigration of each of those elements through the media of living beings is different for each element, consequently, large local variations are expected in the distribution of a single element and for the quantitative determination of the productivity comprehensive analysis of many elements is required which is, of course, a tremendous work. In nature, a universal regularity is frequently observed in the integral effect of many factors, though each of them indicates large fluctuations, so it will be wise to refer the representation of the productivity to such a regularity. In the present paper, an example of such an attempt carried out in the Tanabe Bay, a small bay in Kii Channel along the Pacific coast of Japan is reported.

Through the mechanism of life, living beings fix various elements in their bodies from the sea water, the result of which is the increase of the mass of living beings and the mass of the sea water decreases in the same amount, whatever the materials may be. The time-rate of the mass defect of the sea water will, therefore, be used to represent the amount of production of living bodies. The mass defect of the sea water is expressed as the decrease of specific gravity of the sea water at a certain reference temperature. M. Knudsen derived a well known formula between the specific gravity of the sea water at 0°C (denoted by σ_0) and the chlorinity of the same water (denoted by Cl). This formula is admitted to hold generally well in the entire sea. As the chlorinity is a factor which is least affected by biological activities, the difference between the specific gravity derived from the observed chlorinity (σ_0) and the directly determined one at 0°C (denoted by σ'_0) will offer a useful knowledge of the productivity, because its time-rate measures the integrated consumption of mass by biological activities, though the effect of land water and inorganic processes must also taken into consideration in some occasions. The difference ($\sigma_0-\sigma'_0$) is denoted by $\Delta\sigma_0$ and is called as the specific gravity defect for the reason that the actual water has a specific gravity in defect by this amount to the corresponding Knudsen standard water (in an authors' previous paper, it was called as the excess specific gravity, but the terminology just defined seems to be natural in the present treatment). As the chlorinity is proportional to the salinity, the correlation between Cl and $\Delta\sigma_0$ will reveal a relation between the movement of the sea water and the productivity of living bodies and will be also used for the water mass analysis including biological activities. The authors used this method for the water mass analysis and obtained some interesting results (HAYAMI et al, 1937).

2. Observations of Cl and $\Delta\sigma_0$ in the Tanabe Bay

As a contribution to the problem of the productivity of a bay, the authors attempted an analysis of the correlation between Cl and $\Delta\sigma_0$ in the Tanabe Bay along the line of thought mentioned in the introduction. Two survey lines A and B were taken through the bay mouth of the main bay and through the mouth of a branch bay near the bay head as is shown in Fig. 1. Surface water was sampled by bucket sampler at ten points in nearly equal intervals through each of these lines on board a travelling survey boat. Each group of ten samples was mixed, giving one bottle of 1800 cc. in capacity full of water and represented by it the mean surface

Fig. 1. Key map of the Tanabe Bay

water along respective lines at central epoch of respective traverses. The sampling was made at the depth of about 50 cm below the sea surface. These works were repeated during one complete period of semi-diurnal tide every day from 2nd Nov. 1956 to 8th of the same month. Tidal records were also taken at the same time by self-recording tide gauge at two stations, the one at Seto Marine Biological Laboratory near the bay mouth, the other at Mori near the bay head. The chlorinity was determined with atmost care to 0.01 ‰ by ordinary method of titration using uranine as an indicator. The specific gravity was measured by a specially constructed density meter at a water temperature ranging from 0.5°C to 1°C and reduced to the value at 0°C by Knudsen table, the correctness of which was verified by direct measurements. The accuracy of measurement is about $\pm 2\times10^{-6}$. The results

of measurements are graphically shown in Figs. 2 and 3. In these figures only the values along the line A are shown and the values along the line B will be discussed in the second report, owing to the lack of data. In Fig. 2, the sea level, Cl and $\Delta\sigma_0$ are given, while in Fig. 3 a correlation diagram between Cl and $\Delta\sigma_0$ in seven days is shown. The flow of the sea water through the section A is mainly tidal.

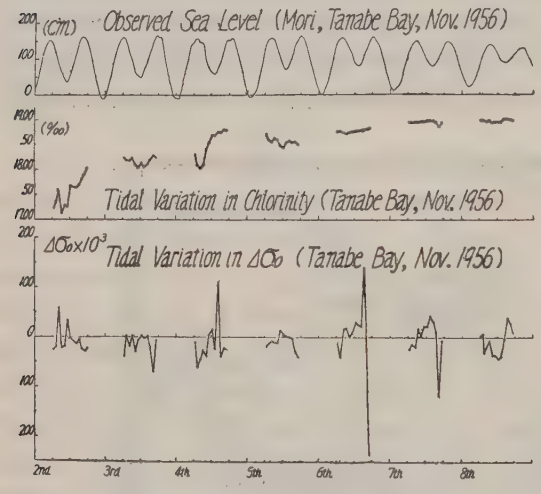

Fig. 2. Tidal variation of sea level, chlorinity and specific gravity defect.

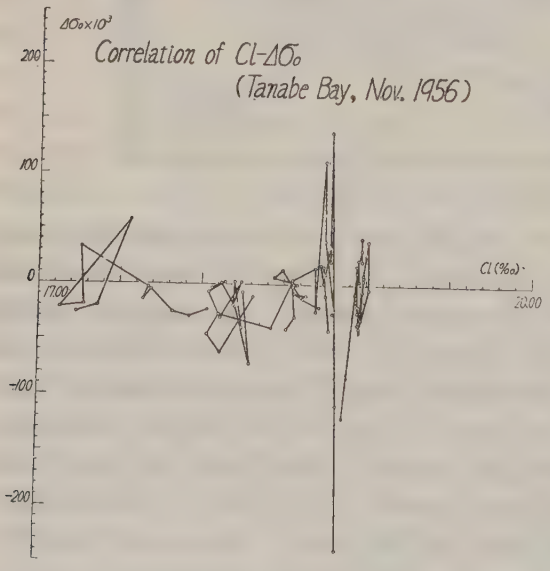

Fig. 3. Correlation diagram between chlorinity and specific gravity defect.

As is seen from Fig. 2, Cl and $\Delta\sigma_0$ indicate a very conspicuous tidal change, though the tidal change of Cl becomes negligibly small after 6th of Nov., while the tidal range of $\Delta\sigma_0$ does not sensibly vary during the entire period of observation. $\Delta\sigma_0$ increases during ebb tide, attaining its maximum at low tide, which indicates that the water in the bay has a remarkable mass defect as compared with the water outside the bay. This defect of mass is independent on the chlorinity. In other words, some content of the sea water is consumed during its stay in the bay. The mass defect seems to increase as the stay of water in the bay. As is shown in Figs. 2 and 3, the tidal cording to the tidal range range of $\Delta\sigma_0$ fluctuates ac- of the sea level. Caused by a long period tide, the mean sea level gradually rises after 6th of Nov. which forces the sea water to stay longer in the bay and during this period, the tidal range of $\Delta\sigma_0$ increases. The relatively small

amplitude in 8th will be explained by the decrease of the tidal range of the sea level. The chlorinity steadily increases to a constant value during the observation period. It is an effect of rainfall. In Table 1, a record of rainfall observed at Seto Marine Biological Laboratory is given where daily value is the amount of rainfall from 8h of the respective day to 9h of the preceding day.

Table 1.

Date 1956	Oct.			Nov.								
	29	30	31	1	2	3	4	5	6	7	8	9
Rainfall (m.m.)	3.9	0	130.5	0	0	0	22.5	0	0	0.53	0.84	0

As the mean depth of the Tanabe Bay is about 17 m, while the tidal range of the sea level is about 1.5 m, the volume of water flowing through the bay mouth is small as compared to the total volume of the bay. If the water in the bay simply moves to and for by the tidal current, the property of water does not change in the mean, but, by virtue of the tidal mixing, the water in the bay will be gradually replaced by the water of the outer sea. This exchange of water may be macroscopically treated as a sort of diffusion. As the mass defect has a gradient towards the bay mouth as is easily inferred from Fig. 2, the mass defect in the bay must diffuse out of the bay, which means under the steady state condition that the same quantity of matter as the mass defect is steadily supplied to the bay from the outside. This amount of flux can be treated quantitatively by the equation of diffusion. As the flux of mass defect represents the productivity of a bay, the diffusion equation of mass defect may be taken for the equation of productivity.

3. Diffusion equation of mass defect

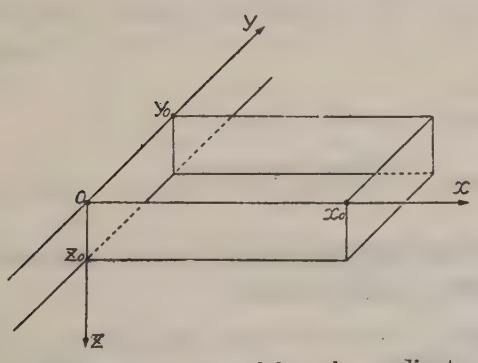

Fig. 4. Bay model and coordinate system.

As a working model, we take a rectangular bay of uniform cross section and uniform depth and take coordinate axes as are shown in Fig. 4. We denote mass defect in a unit volume of the sea water by q and the net consumption of mass in a unit volume of the sea water in a unit time which is another indicator of the productivity by c. Then the diffusion equation of q under no mean current is given by

$$\frac{\partial q}{\partial t}=\eta_1\frac{\partial^2 q}{\partial x^2}+\eta_2\frac{\partial^2 q}{\partial y^2}+\eta_3\frac{\partial^2 q}{\partial z^2}+c \qquad (1)$$

where η_1, η_2 are the coefficients of horizontal mixing and η_3 is that of vertical one. The boundary conditions of q are

$q=0$ at $t=0$

$\partial q/\partial z=0$ at the surface and the bottom

$\partial q/\partial y=0$ at the bay side

$\partial q/\partial z=0$ at the bay head

and $q=0$ at the bay mouth.

Integration of (1) from the surface to the bottom and from one side to the other gives

$$\frac{\partial Q}{\partial t}=\eta_1\frac{\partial^2 Q}{\partial x^2}+c \qquad (2)$$

where Q and C are the mean value of q and c respectively in a cross section of the bay. The boundary conditions of Q are

$Q=0$ at $t=0$

$Q=0$ at $x=0$

and $\partial\theta/\partial x=0$ at $x=x_0$.

Horizontal mixing is mainly due to the tidal mixing, so η_1 may be put as (STOMMEL et al, 1951)

$$\eta_1=\alpha u l \qquad (3)$$

where u the mean speed of tidal current from slack to slack and l is the path of water volume during half period of tide i.e. $l=uT/2$, T being the period of tide. According to the authors' research in Akashi Strait (HAYAMI et al, 1957), α is nearly equal to 0.1.

Solution of (2) satisfying the boundary conditions is given by:

Case 1. C is constant.

$$Q=\sum_0^\infty \frac{4c}{(2n+1)\pi}\sin\frac{(2n+1)\pi}{2x_0}x\int_0 exp\left\{-\frac{\eta_1(2n+1)^2\pi^2 t}{4x_0^2}\right\}dt \qquad (4).$$

Case 2. C varies with time.

$$Q=\sum_1^\infty \frac{4}{(2n+1)\pi}\sin\frac{(2n+1)\pi}{2x_0}x\int_0^t C(\tau)exp\left\{-\frac{\eta_1(2n+1)^2\pi^2(t-\tau)}{4x_0^2}\right\}d\tau \qquad (5)$$

For a practical purpose, we may use the first term ($n=0$) as an approximation of these solutions. In the steady state, we have

$$\eta_1\frac{\partial^2 Q}{\partial x^2}+C=0 \qquad (6).$$

Solution of (6) is given by

$$Q=\frac{c}{\eta_1}\left(x_0 x-\frac{1}{2}x^2\right) \qquad (7)$$

that is, the distribution of Q along the bay axis is parabolic. The flux of mass defect through the cross section of the bay mouth is given by the integration of (6) from $x=0$ to $x=x_0$, that is

$$A\eta_1\left(\frac{\partial Q}{\partial x}\right)_0=AC_0x_0 \qquad (8)$$

where A is the cross sectional area and C_0 is the mean value of C along the bay axis. In order to calculate the amount of flux or mean consumption, the value of η_1 must be known. The effect of rainfall upon the chlorinity makes this possible to some extent.

4. Estimation of η_1

The dilution of the chlorinity by the rainfall gradually recovers with time as is shown in Fig. 2. We assume this recovery is due to the tidal mixing. Then the change of the chlorinity will be given by (6) in putting $C=0$ and assuming Q to be the decrease of the chlorinity by dilution. The boundary conditions of Q may be put as

$$\begin{aligned} Q&=Q_0 \quad \text{at} \quad t=0 \\ Q&=Q_1(t) \quad \text{at} \quad x=0 \\ \partial Q/\partial x&=0 \quad \text{at} \quad x=x_0 \end{aligned}$$

where Q_0 is a certain numerical constant and $Q_1(0)=0$.

If $Q_1(t)$ varies slowly with time, the solution satisfying these conditions is nearly expressed by

$$Q=Q_1+\sum_0^\infty \frac{4Q_0}{(2n+1)\pi}\sin\frac{(2n+1)\pi}{2x_0}x\ \exp\left\{-\frac{\eta_1(2n+1)^2\pi^2 t}{4x_0^2}\right\} \qquad (9).$$

We may use the first term of (9) with sufficient accuracy.
Then

$$Q\cong Q_1+\frac{4Q_0}{\pi}\sin\frac{n}{2x_0}x\exp\left(-\frac{\eta_1\pi^2}{4x_0^2}\right) \qquad (10)$$

or

$$Q-Q_1\cong\frac{4Q_0}{\pi}\sin\frac{n}{2x_0}x\exp\left(-\frac{\eta_1\pi^2 t}{4x_0^2}\right)=K\exp(-kt) \qquad (10)'.$$

If we denote the mean chlorinity in the bay and at the bay mouth by Cl(t) and Cl′(t) respectively and assume the bay water which had originally

the same chlorinity with the outerw ater was suddenly diluted at $t=0$ by the inflow of land water due to the rainfall, then as the direct effect of the rainfall over the sea surface is alike everywhere, we may put

$$Q = Cl'(0) - Cl(t)$$
$$Q_0 = Cl'(0) - Cl(0)$$
$$Q_1 = Cl'(0) - Cl'(t)$$

hence, $$Q - Q_1 = Cl'(t) - Cl(t).$$

If we assume the time change of Cl′ is small as compared with that of Cl, then by differentiating (10)′ with respect to t, we get

$$\frac{\partial Cl}{\partial t} = Kk \exp(-kt) \qquad (11).$$

Taking logarithm of both side of (11),

$$lg \frac{\partial Cl}{\partial t} = lg\, K k - kt \qquad (12).$$

Using observed daily mean values of Cl, we get from (12)

$$k = 0.6 \text{ (1/day)}$$

and $$K (\equiv Q_0) = 3.33 (‰).$$

Putting $x_0=5$km in (10)′, we get from the value of k

$$\eta_1 = 7.05 \times 10^5 \text{ (c. g. s.)}.$$

Assuming the relation (3) and putting $\alpha = 0.1$ and T=12hr, we get further

$$u = 18 \text{ (cm/sec)}$$

which seems to be of right order in this bay.

5. Estimation of the flux of mass defect

Using the values of k and K and the observed value of the mean chlorinity, we get from (10)′ the value of Cl′ which is given in Table 2.

Table 2.

Date Nov. 1956	2	3	4	5	6	7	8
Cl′ (‰)	18.55	18.72	18.80	18.74	18.82	18.99	19.00

Extrapolating the value of Cl′, we get

$$Cl'(0) = 17.90 \text{ (‰)}$$

hence, $$Cl(0) = 14.57 (‰).$$

The catchment basin of the Tanabe Bay is about $12.4\times10^{11}cm^2$— about 5.9 times of the bay area. If we assume the direct surface flow of the rain water pouring into the bay to be half of the total amount of the rainfall, then, as the rainfall on 31st Oct. amounted to 13 cm, the fresh water poured into the bay gives the depth of about 40 cm to the bay area. This water mixes with the sea water of chlorinity 17.90 ‰ and reduces the chlorinity to 14.57 ‰, hence it results in the homogeneous surface mixing layer of about 1.7 m in thickness. The estimated value of η_1 is only applied to this layer and the sampling of water was also made in this layer.

The mean tidal range of $\Delta\sigma_0$ may be taken for the change of $\Delta\sigma_0$ against the change of x by l. Putting the mean tidal range of $\Delta\sigma_0$ as 80×10^{-6} and assuming $\Delta\sigma_0$ to be eighty percent of Q, we get

$$\left(\frac{\partial Q}{\partial x}\right)_0=2.58\times10^{-10}\ \text{(c. g. s.)}.$$

Hence, the flux of mass defect across the cross section of the mixing layer through the bay mouth is

$$A_1\eta_1\left(\frac{\partial Q}{\partial x}\right)_0=4.9\times10^5\ \text{(ton/year)}$$

where A_1 is the cross sectional area and is given 8.5×10^7 cm^2, the spun of the bay mouth being 5×10^5 cm. Then, from (8), we get in the mixing layer

$$C_0=38.6(g/m^3.\ day).$$

The amount of flux is fairly large. The present estimation is made under many assumptions, so it gives only the order of magnitude. From the comparison of the flux of water volume and the tidal change of the sea level, it will be supposed that the consumption takes place mainly in the mixing layer, but the present observation which is exclusively limited in the surface layer does not give any detailed information on the processes going on in the deep layer of the bay. Basing on the observations in the deep layer the authors wish to discuss this point in the second paper.

Acknowledgement

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A STUDY ON THE PRODUCTIVITY OF THE TANABE BAY
(Part I)

IV. On Some Plankton Indicating the Water Exchange in the Tanabe Bay

By Isamu Yamazi
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1. Introduction

Plankton organisms are generally distributed at the mercy of water movements in the area where they live. Therefore, they might be used as indicators of water masses or currents, if the details of their regional distributions and the sources of their distribution are known. Especially the inlet plankton communities show the characteristic regional features. Several species of copepods, chaetognaths and tunicates and some larval forms of benthic animals are found exclusively in inlet waters, but they are scarcely found in the open sea water neighbouring the inlet water. The neritic or oceanic plankton communities in the open sea water are carried into the inlets and there they may be maintained in a certain region of the inlet. The distribution and maintenance of local autogenetic or allogenetic population depend on the dynamic balance between the translocation and dispersion of the population caused by water movement and the reaction of the population to environmental changes caused by the water movement.

Fig. 1. Map of the Tanabe Bay showing the stations during the 9th~11th, November, 1956.

For the purpose to prove this principle by myself, I have devoted myself to clarify the plankton distribution in inlet waters along the Japanese coasts, and this paper concerns with the distribution of plankton communities in the Tanabe Bay. The Tanabe

Bay is an inlet facing to the Kii-channel through a wide mouth, and its maximum depth of about 35 meters lies near the entrance. Its bottom configuration is complicated by many islets and rocks of various shapes and sizes scattered here and there (Fig. 1). Five arms are formed at the inner part of the bay. The tidal range in the bay is rather great, about 1.8 meters in extent at the time of spring tide, and the current outside the bay is relatively strong.

2. Material and Method

The samples of the present survey were collected during the 9th-11th of November, 1956 at one hundred stations in the Tanabe Bay, which are shown in Fig. 1. They were hauled vertically from 15 meters to the surface or from the depth near the bottom to the surface at those stations shallower than 15 meters, by a small net, a modified *Kitahara's* quantitative silk tow net, whose diameter at the mouth and at the largest part is 11.2 cm and 25 cm respectively and the length is 70 cm. It is stretched with the *Müller's* gauze No. XX-13, and may cut by its mouth about 10 liters of water by one meter haul. The settling volume of every sample was roughly measured with a cylinder after 24 hours' sedimentation. Of course large organisms such as salps and medusae were removed from the samples before they were measured.

3. Plankton Indicators in the Tanabe Bay

1. *Local autogenetic plankters.*

Autogenetic plankters are represented by copepods *Oithona nana, Oithona rigida, Paracalanus parvus* and their nauplii; tunicate *Oikopleura dioica;* chaetognath *Sagitta delicata;* pelecypod and gastropod veligers.

2. *Allogentic plankters.*

Oceanic or coastal forms of four chaetognath species, three tunicate species and twenty copepod species are treated here, besides an important species of copepod *Oithona similis* and a diatom *Coscinodiscus weilesii.*

The former species are richly found in the Tanabe Bay, generally decreasing towards the outer areas, though they may be seen in a small number in the coastal water neighbouring the bay. Contrarily, the latter species decrease in number toward the inner area of the bay. The outline of the distribution of above-mentioned plankters in the Tanabe Bay is given below.

Oithona nana: This is a small copepod with a wide distribution, occurring most abundantly in this bay; it occurs sparsely in the coastal water close to the bay, but never in the off-shore or oceanic water. Generally, it is found more abundantly in the water of comparatively

Fig. 2. Distribution of the settling volume of plankton (cc per one meter haul) at each station.

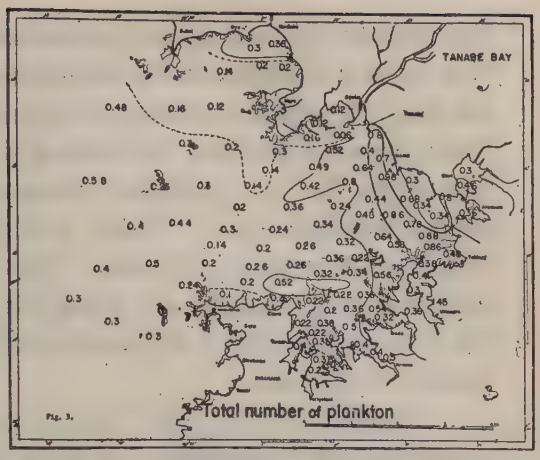

Fig. 3. Distribution of total number of plankton per one meter haul. Unit of number is thousand.

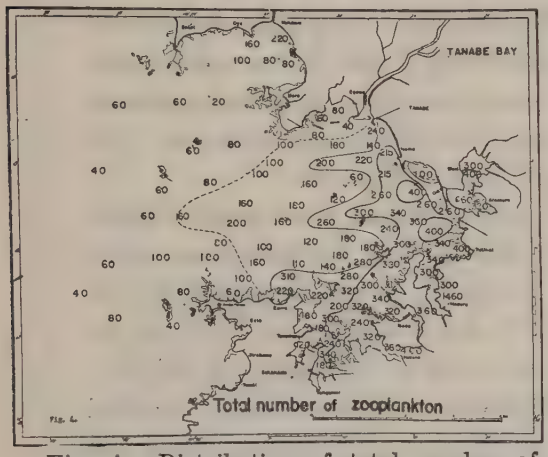

Fig. 4. Distribution of total number of zooplankton per one meter haul.

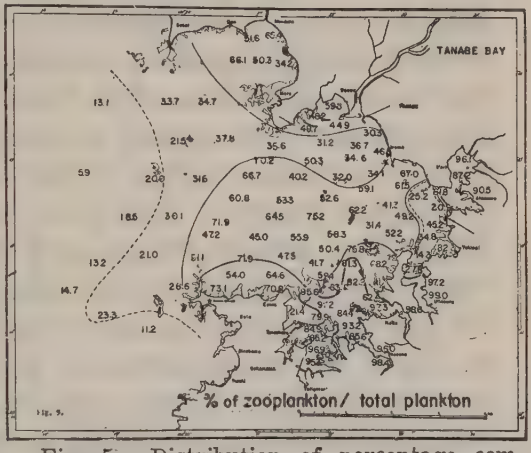

Fig. 5. Distribution of percentage composition of zooplankton per total plankton.

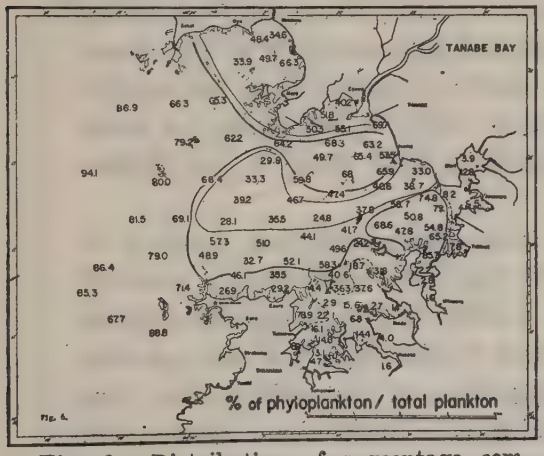

Fig. 6. Distribution of percentage composition of phytoplankton per total plankton.

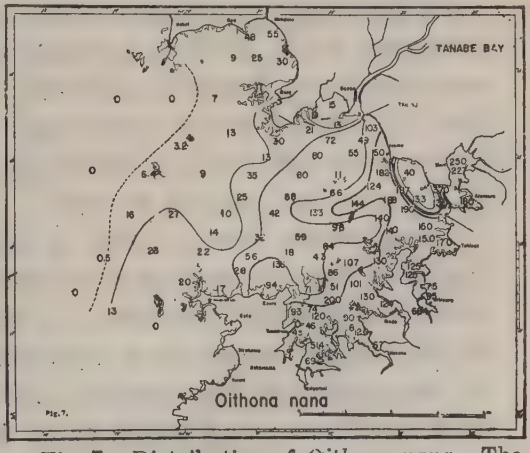

Fig. 7. Distribution of *Oithona nana*. The number indicate per one meter haul.

low salinity in inlets or near estuaries. As is shown in Fig. 7, the population of this copepod varies conspicuously from area to area throughout the bay. It occurred most densely in and around the northeastern baylets. More than one hundred individuals were caught by one meter haul in the area inside the line connecting Isoma on the northeastern coast with Ezura on the southern coast. There is also a tongue-like extension extending towards the center of the bay. The water containing dense *O. nana* was observed in a narrow area along the northern and southern coasts. On the other hand, only a few specimens were met with at stations near the mouth of the bay.

Paracalanus parvus: Two distinct morphological and ecological types of this cosmopolitan species are distinguished in the Japanese waters. One is the minor form thriving in inlet or bay waters and the other is the major form found in the outer part of the inlet or in the coastal waters. In the Tanabe Bay (Fig. 8), the minor form was found at all stations, the greatest concentration being found in the area inside the line connecting Isoma with Ezura, where the water is rather stagnant and of relatively low salinity as compared with that of the open sea. The major form occurred chiefly in the outer area of the bay.

Sagitta delicata: This is an important littoral chaetognath distributed in the estuarine water of lower salinity and the sheltered water close to the land in the warmer region of Japan. In the Tanabe Bay it is the only local chaetognath surviving in its innermost area. As is shown in Fig. 9, the largest population of it occurred in five arms of the bay, and as in the case of *Oithona nana*, the boundary of its distribution showed a tongue-like extension from the coast of the city of Tanabe. Along the southern coast of the bay the boundary of the distribution extended toward the mouth, though only several individuals were caught there by one meter haul. Several specimens occurred independently at the innermost station in Matubara inlet on the northern coast. It is noteworthy that the smaller forms were found more richly in the innermost area. These facts seem to show that this species is more fitted to and thrives in the innermost part of the bay.

Oikopleura dioica: This is the only appendicularian common to Japanese inlet waters, being distributed widely in the littoral or brackish waters of different salinities. In the Tanabe Bay it occurs abundantly in the warmer season from early summer to autumn. Tokioka reported in his paper on the plankton investigation of the Osaka Bay that this species was very useful as an indicator of inlet water masses. In the Tanabe Bay (Fig. 10) its distribution is restricted mainly to the inner half of the bay inside the line connecting Isoma with the cape of Bansyo-

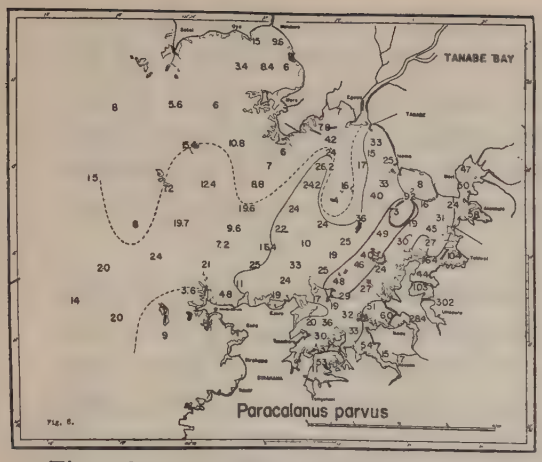

Fig. 8. Distribution of *Paracalanus parvus*. The number caught per one meter haul.

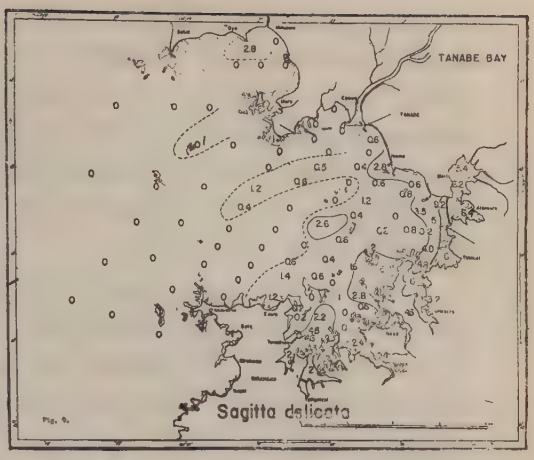

Fig. 9. Distribution of *Sagitta delicata*. Number per one meter haul.

Fig. 10. *Oikopleura dioica*. Number per one meter haul.

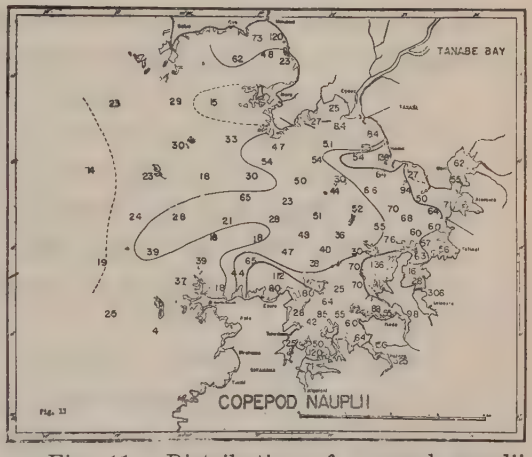

Fig. 11. Distribution of copepod nauplii. Number per one meter haul.

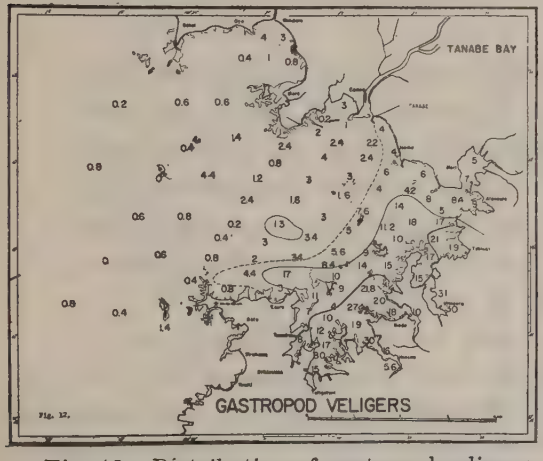

Fig. 12. Distribution of gastropod veligers. Number per one meter haul.

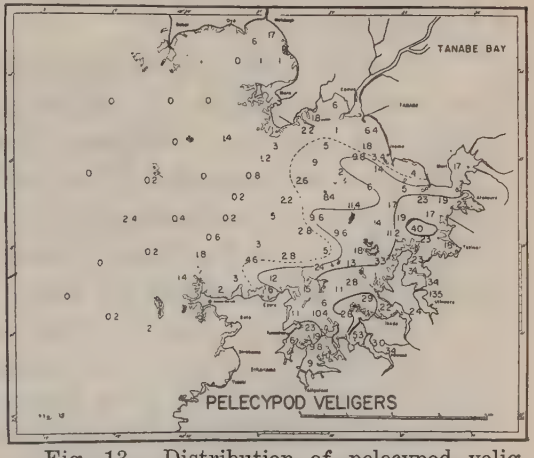

Fig. 13. Distribution of pelecypod veligers. Number per one meter haul.

no-hana, although it is found sparsely at stations in Matubara inlet, too. A large number of this tunicate are hauled in the innermost areas of five arms, most of which were small-sized young specimens. The density decreases towards the mouth of these arms, but the distribution area covers the outer stations near the southern shore, near the islet of Kasima off Utinoura arm and along the northern coast. Young specimens are not found in these outer areas.

Copepod nauplii: Copepod nauplii consisting chiefly of larvae of such inlet water species as *Oithona nana, Paracalanus parvus* and *Acartia erythraea* are found throughout the bay in a much greater number than other larval forms. They are found most abundantly in the inner area and decrease towards the open sea, though a relatively rich population is seen also in the northern and southern coastal areas in the eastern half of the bay. The nauplii of *Oithona nana* are the most important of all, and then followed by those of *Paracalanus*. Nauplii of *Acartia* are surprisingly scarce as compared with the size of the adult population (Fig. 11).

Gastropod veligers: They are distributed widely and abundantly (Fig. 12), and most of them are in post-larval stages. The densest population is found in the inner area of the southern inlet. The veligers met with at stations near the mouth of the bay are considered to have been carried from different sources other than those in the inner areas, though the specific identification on these veligers and larvae are quite inaccessible for me.

Pelecypod veligers: Pelecypod veligers are found numerously in the inner area which harbours many inlet water plankters mentioned above (Fig. 13). The largest number is met with in the southern inlets and the boundary of distribution shows three outward extensions, namely southern, central and northern ones. At stations near the mouth, they are scarcely found.

Oithona rigida: Two dense patches of a small copepod *Oithona rigida* are shown in Fig. 14, i.e., off the cape Bansyo-no-hana and in Matubara inlet. Its maximum population reaches about 500 at the former patch. It is found very sparsely in the northern and southern coastal areas, but none in both the innermost part of the bay and the open sea water outside of the bay. The formation of such enormously dense patches seems to allude that the spawning was going on at that time.

Coscinodiscus wcilesii: This diatom is distributed widely as well as densely in the open sea water outside the bay, but quite sparsely in the central areas of the bay (Fig. 15). A large patch of comparatively dense concentration is found extending from the coast of the city of Tanabe to Takinai inlet. Small populations of this diatom occur in five arms, the

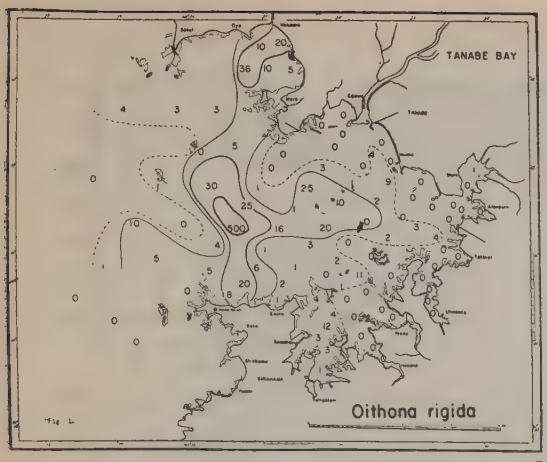

Fig. 14. Distribution of *Oithona rigida*. Number per one meter haul.

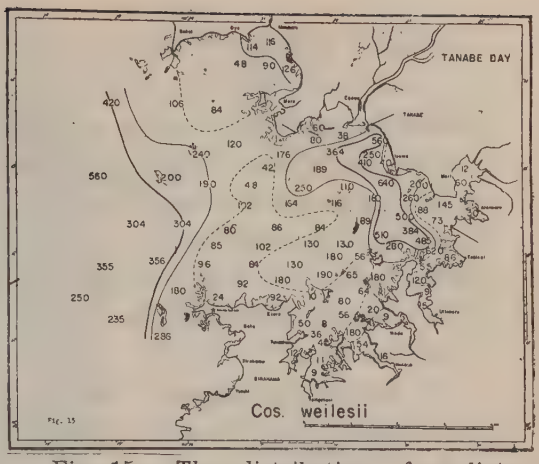

Fig 15. The distribution of a diatom *Coscinodiscus weilesii*. Number per one meter haul.

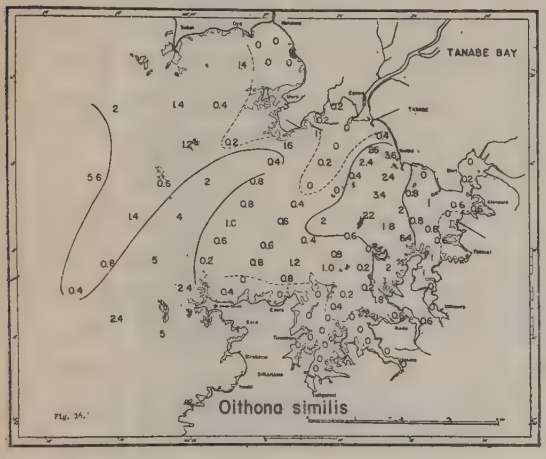

Fig. 16. Distribution of a copepod *Oithona similis*. Number per one meter haul.

Fig. 17. Distribution of off-shore copepods. Number per one meter haul.

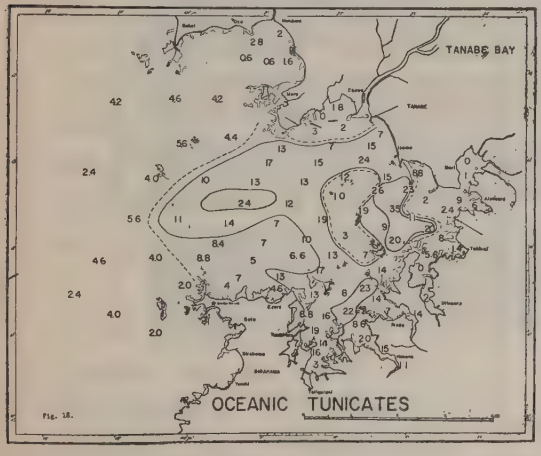

Fig. 18. Distribution of oceanic tunicates. Number per one meter haul.

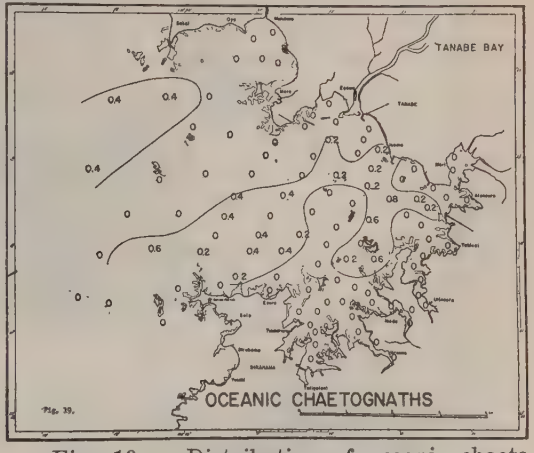

Fig. 19. Distribution of oceanic chaetognaths. Number per one meter haul.

southern area of the bay near Ezura, and the northern area near Egawa.

Oithona similis: This is an eurythermal and euryhaline copepod distributed widely but in a small number in more off-shore areas than those where the foregoing animals are distributed. As is shown in Fig. 16, it is found most abundantly near the entrance to the bay and decrease towards the inner areas. It is almost absent in southern arms and innermost parts of northern arms. A relatively large patch is found off Isoma; the distribution pattern resembles somewhat that of *Coscinodiscus weilesii*.

Oceanic copepods: Twenty species (*Calanus tenuicornis, Cal. finmarchicus, Cal. darwinii, Calocalanus pavo, Eucalanus mucronatus, Candacia truncata, Can. catula, Labidocera acuta, Lab. detruncata, Acartia danae, A. neglecta, Paracalanus aculeatus, Oithona plumifera, Setella gracilis, Clitemnestra scutellata, Sapphirina opalina, Corycaeus agilis, Corylongistylis, Cory. acutus* and *Copilia mirabilis*) are treated together. They are widely distributed, but far less abundantly than the preceding copepods (Fig. 17). Large populations are found near the southern half of the entrance to the bay, but none in the innermost parts of arms.

Oceanic tunicates: Four species (*Oikopleura longicauda, Oiko. rufescens, Stegosoma magnum, Fritillaria haplostoma*) are treated together. This group occupies the major part of the open sea plankton in this bay. The greatest concentration (Fig. 18), comprising both *Oikopleura* and *Fritillaria*, is observed near the center of the bay and another large patch extends from Isoma to the mouth of Takinai arm. A smaller patch is found extending from the mouth of Hosono arm to that of Ikeda arm. They are most scarce near the islet of Kasima and in narrow arms. These tunicates seem to be able to survive for a considerably long time in inlet water masses. Their distribution within the bay seems to indicate the mixing degree of the open sea water with the stagnant inlet water.

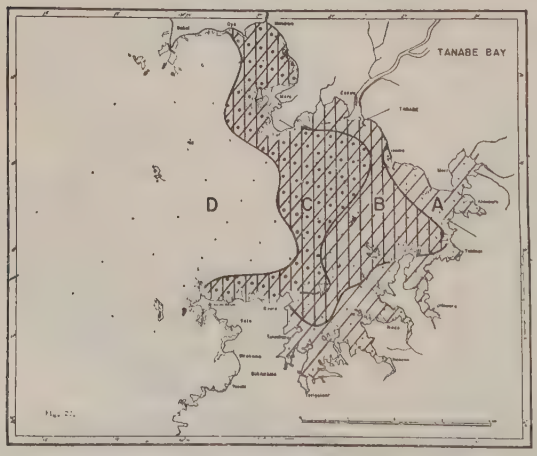

Fig. 20. Percentage composition of important copepods at each station in Tanabe Bay during November, 9~11, 1956.

Oceanic chaetognaths:

These forms (*Sagitta enflata, S. minima, S. neglecta, S. serratodentata*) are treated together. Oceanic chaetognaths are hauled only in

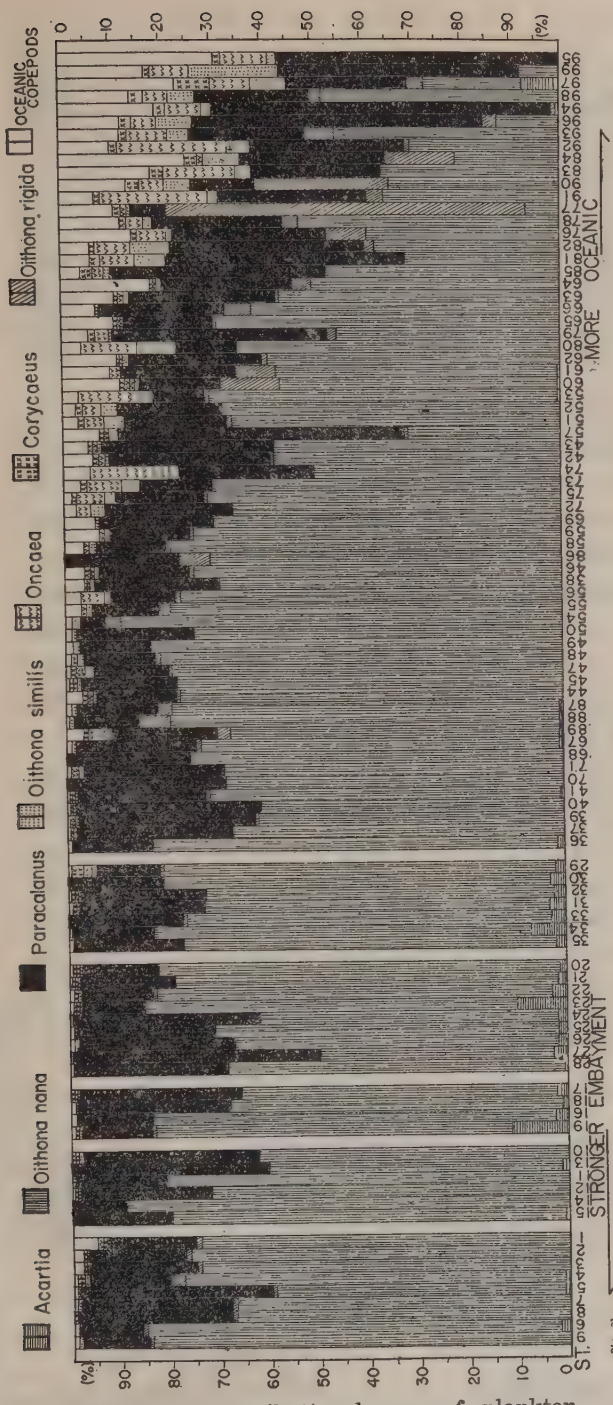

Fig. 21. Distributional map of plankton communities in Tanabe Bay during the period of November 9~11, 1956.

small numbers. They are found chiefly at the central area of the bay extending from Isoma to the islet of Hatake-zima off Ezura (Fig. 19). They occur at 28 per cent of all stations, being quite absent in the inner areas and the northwest part of the bay.

4. Discussion

Biological Characteristics of Tanabe Bay: The distribution of plankton is associated closely with the hydrographical conditions of the bay. The plankton of the Tanabe Bay during the present survey seem to be classified into the following four communities, each of which is dominated by copepod populations (Figs. 20 and 21).

"A" community: The stagnant water kept in the inner areas or the five arms of the bay was richly populated by *Oithona nana*, which was associated with *Sagitta delicata, Oikopleura dioica,* pelecypod and gastropod veligers, nauplii and copepodid of inlet-water-copepods, all of which are originated in the inlet water. Both the settling volume and the total number of zooplankton were very large in the area occupied by this community (Figs. 2, 3~5). The biological productivity seems to be the highest in this

area throughout the bay.

"B" and "C" communities: The central area of the bay was occupied by a large number of *Oithona nana, Paracalanus parvus* and *Oithona similis*. These communities were associated on one hand with members of the "A" community, and on the other hand with a small number of oceanic or coastal water forms of *Oikopleura, Fritillaria, Sagitta* and copepods and also of a diatom *Coscinodiscus weilesii*. The settling volume and the total number of plankton were relatively large in the area occupied by these communities (Figs. 2, and 3~5). The biological productivity is relatively large in this area, too.

"D" community: The outer part of the bay is characterized by the dominance of the mixed population of the open sea and inlet water forms. The oceanic forms comprise *Oncaea, Corycaeus,* major form of *Paracalanus parvus,* the other copepods, chaetognaths and tunicates, and the inlet forms include *Oithona nana* and *Paracalanus parvus* which occur, however, much less abundantly than in the inner communities. The inlet forms such as *Sagitta delicata* and *Oikopleura dioica* were quite absent or found only very sparsely in this area. Both the settling volume and the total number of plankton were very small. The biological productivity seems to be the lowest in this area throughout the bay.

From these results it is obvious that the plankton of the Tanabe Bay is influenced strongly by the open sea water excepting the relatively narrow inner areas. And resultantly, as is shown clearly in the regional distribution of plankton communities, the biological productivity of the bay seems to be comparatively small for the size of the bay. This is evidently due to the topographical characteristic of this bay with a wide entrance

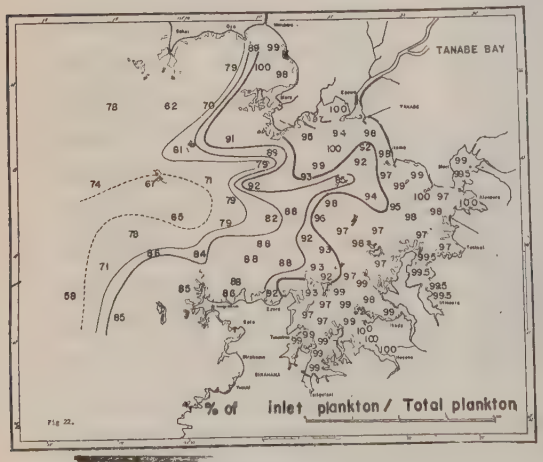

Fig. 22. Distributional map of the percentage composition of the local copepods per total number of copepods.

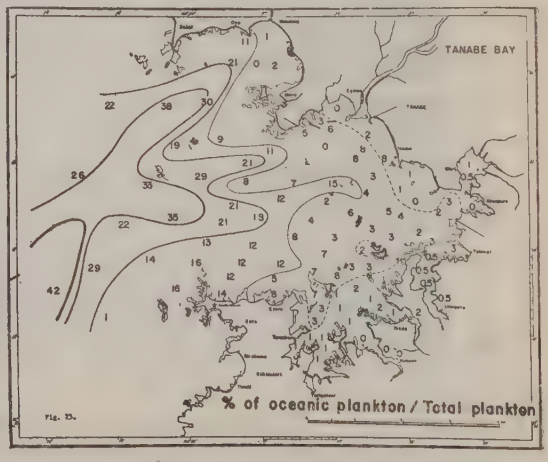

Fig. 23. Distributional ma of percentage composition of the allogenetic population consisting of both oceanic and coastal copepods per total number of copepods.

opening to the open-sea. However, the complicated coast line in the inner part of the bay and the scattered islets, rocks and reefs prevent the strong influx of the open-sea water into the inner part of the bay and maintain the stagnant water and high biological productivity.

Current System as inferred from Plankton Distribution: By comparing the distributions of plankton with those of hydrographic conditions, some interesting correlations are found. The courses of water movement as indicated by the distribution of plankton communities agree well with those traced by drift bottles by Mr. Nakamura. Summarizing the observations on the distribution of inlet-water and open-sea-forms of plankton, I give here the distributional maps of the percentage composition of these forms (Figs. 22 and 23). The stations with large percentage of inlet-water-forms occur in the inner and narrow arms, and tongue-like extentions with decreasing percentage towards the open sea are found off the city of Tanabe, near the southern shore, near the islet of Kasima and along the northern coastal areas. On the contrary, off-shore forms are found most abundantly near the entrance of the bay and extend towards Egawa, Isoma and near Hatake-zima. It is possible to trace the open-sea-forms in the inner part of the bay, though their components are very few. The presence of a large patch with many oceanic forms on the northeastern part of the bay is due to the influx of outside water masses. The difference of the nature of water-masses between the northeastern and southern parts of the bay is clearly traced by the difference of the local stock and oceanic forms of plankton contained in them.

5. Summary

1. The regional distribution of plankton in the Tanabe Bay during the autumn of 1956 is discussed.

2. The Tanabe Bay is characterized by the dominance of copepod populations. The bay is divided into four areas with characteristic plankton communities and its productivity is discussed.

3. The variation of the plankton population is closely correlated with the hydrographical and topographical conditions. The water movement is analyzed from the regional distribution of plankton communities.

4. The following species are employed as indicators of water masses;

a). Among the indicators for inlet water masses are such local autogenetic species as *Oithona nana, Paracalanus parvus,* copepod nauplii of the local stock, *Oikopleura dioica, Sagitta delicata,* pelecypod and gastropod veligers and *Oithona rigida.*

b). As the indicators for the open sea water masses, which are characterised by coastal and oceanic species, there are such species as *Oithona similis, Oncaea, Corycaeus,* oceanic copepods (twenty species), oceanic tunicates (three species), oceanic chaetognaths (four species), and a diatom *Coscinodiscus weilesii.*

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(Part I)

A STUDY ON THE PRODUCTIVITY OF THE TANABE BAY

V. Distribution and Abundance of Rocky Reef Fishes in the Tanabe Bay

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Shin-ichiro Fuse and Eiji Harada**
(Seto Marine Biological Laboratory, Kyoto University) (Zoological Institute, Kyoto University)

1. Introduction

Many workers have contributed to the knowledge of the bottom fauna or the plankton communities in bays, but the fish fauna is as yet imperfectly understood, especially from the ecological point of view.

In this paper we have investigated the distribution of fishes in the Tanabe Bay with special reference to the relations among their abundance, size and habitat. This study is a part of the basic survey on the productivity of the sea, sponsored by the Japanese National Commission for UNESCO, and carried on under the integrated cooperation by oceanographical and planktological students. Owing to the bad weather during the period of survey between November 13 and 17, 1956, however, we were only able to gain some data from the southern and innermost parts of the Tanabe Bay.

Because of the parctical convenience we took data only of those fishes that were inhabiting in the rocky reef area or its immediate vicinities. Some of these fishes are good game fishes as well as important commercial fishes.

Although the data gained through this study leave much to be explained and added, the results presented here may provide available in-

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formations to the basic study on the biological productivity of the sea with some economic implications.

2. Methods and Stations

All the data presented and discussed in this paper were gained from the direct observation by diving with the aid of SCUBA. After seeking a place at each station, where the fishes were relatively abundant—since the fishes do not occur uniformly in a reef, but in general appear aggregated according to the topographical feature of the reef—records of the species, their size and approximate number were made under water. Size was recorded in each 5 cm class by the rough estimation of their body length. Further, supplemental observation by swimming around as wide as possible was made to record other fishes. At the same time, the topographical feature of the reef was described.

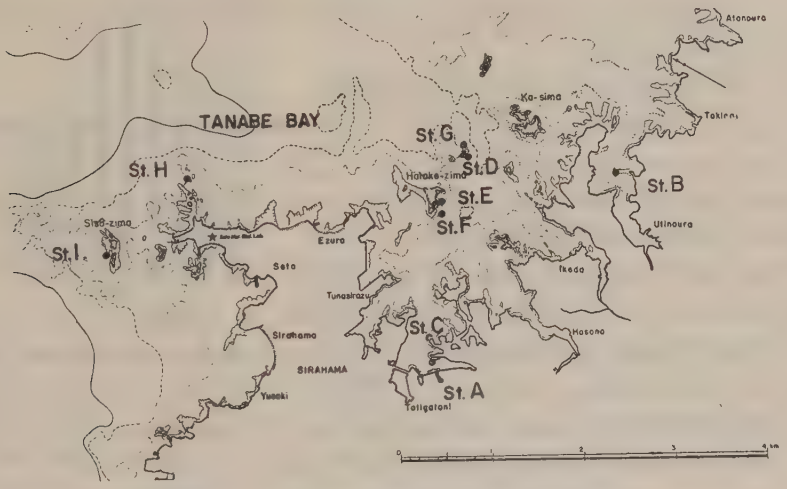

Fig. 1. Map showing diving stations.

Diving stations are shown in Fig. 1. As to conditions of water in the bay, the readers are referred to the foregoing article on oceanographic conditions. The specific conditions with respect to their topographical feature are sumarized in Table 1. In the innermost part of the bay, extension (broadness), roughness (unevenness), and height of cliff in the reef are all in smaller degree, the mud-covering over the reef is thicker, and turbidity of water is greater than at the mouth or out of the bay, while in the middle of these two parts all these conditions are intermediate. Thus, it is evident that the abiotic environmental condition varies keeping a conspicuous tendency from the inner to the outer part of the bay.

3. Fish Fauna

The total number of species observed is fifty-nine, of which important species are shown in Table 2. Some fishes, e.g., *Mugil cephalus* Linné (Japanese name: Bora) which is an occasional visit to the reef, must not be treated as the rocky reef fish, if their natural habitants are muddy or sandy bottom. So are the migratory swimmers, too.

Fishes usually inhabiting in rock crevices or rock holes are considered to be missed often, for they seldom swim out of their hermitages, and it is impossible to peep into every one of those habitats. Further, the rare species are not always met with during a diving observation. All these fishes are not shown in Table 2, and excluded from the data on which the following discussions are made.

4. Discussion

The following discussions are made on the data of thirty species presented in Table 2.

Mode of the distribution of each species

Four main types as to the mode of the distribution of rocky reef fishes in the bay are recognized as follows:

a) Restricted to the innermost part of the bay: 2 species—*Rudarius ercodes* and *Mylio macrocephalus*.

b) From the innermost part to outside of the bay: 6 species — from *Girella punctata* to *Prionurus microlepidotus* in Table 2.

c) From the middle part to outside of the bay: 15 species—from *Chromis notatus* to *Microcanthus strigatus* in Table 2.

d) Restricted to the outer part of the bay: 1 species—from *Choerodon azurio* to *Lethrinus choerorhynchus* in Table 2.

As we go diving from the innermost part to the outer part of the bay, the first fishes to be met with are those of types and b, then fishes of type c are added to them and fishes of type a disappear, and lastly fishes of type d are added furthermore. Thus, the number of species of the rocky reef fishes increases one by one from the inner to the outer part of the bay, except type a.

In Miyadi's studies (1938, 1940a and b), the benthic fauna of the Tanabe Bay was classified into two major communities, viz., *Maldane*-community which extended from the middle part to the outer part of the bay, and *Proclava*-community occupying the inner part of the bay. Habe (1950) pointed it out as a characteristic nature of the molluscan fauna in this bay that Molluscs of oceanic nature and of week embayment degree and those of the strong embayment degree are in contact with

each other on a line connecting Hatake-zima and Ka-sima, having no gradual transitory zone. The distribution pattern of their rocky reef fishes and that of the benthic fauna in the basin of the bay are definitely different.

Relationship between size of fishes and their distribution

These fifty-nine species of the rocky reef fishes may be divided into three classes conveniently according to their adult size, namely, the small class (below 15 cm in body length), the middle class (between 20 cm and 40 cm) and the large class (above 50 cm). Number of species belonging to each class in each station are shown in Fig. 2.

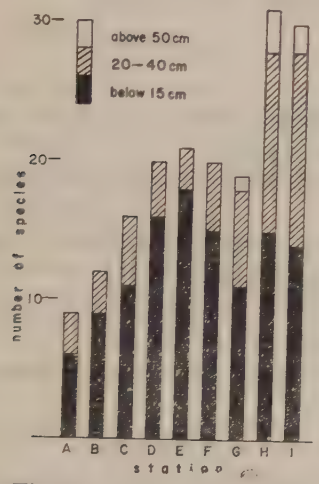

Fig. 2. Composition of the rocky reef fish fauna at each station according to the class of body length.

The number of species of the small class increased from Station A to Station E, but not from Station F to Station I, while remarkable change occurred in the middle class. The number of species of the middle class increased at Station F and multiplied approximately by two at Station H suddenly. At the same station the fishes of the large class also appeared.

Through the examination of observed body length of fishes belonging to the middle class, it is evident that their young fishes inhabit in the inner part as well as the outer part of the bay, but adult fishes inhabit only in the outer part. That is to say, as going from the inner part to the outer part of the bay, the larger species of the same species as well as larger fish species are added one by one.

In other words, in the inner part of the bay larger species and larger individuals of the rocky reef fishes are not able to inhabit.

Types of the reef in Tanabe Bay as habitats of the rocky reef fishes

In Table 2 and Fig. 2, remarkable differences in the rocky reef fish fauna are shown between Station C and D, and between Station G and H. Stations A-C are in the arms of the bay, Stations H-I are in the outer part of the bay, and Stations D-G are in the middle part of the bay. The reefs as habitats of rocky reef fishes are distinguished in three types mentioned above. Further, the conspicuous differences are also shown between Stations D-E and Stations F-G, although these stations are very near with each other. It is particularly interesting that Station D and Sation G are on opposite sides of the same reef to each other.

5. Conclusion

These results described above undoubtedly suggest that the rocky reef fishes are distributed with close relation to environmental conditions, especially to the topographical conditions of the reef, though their mode of distribution differs from that of the benthic animals. Further, the quantity and quality of food animals for these fishes might have influence on the distribution of the latter, although this was not investigated in the present study. Thus, it may be supposed that there exists an principle unique to the distribution and abundance of the rocky reef fishes.

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Table 1. Environmental conditions of diving stations.

Station	A	B	C	D	E	F	G	H	I
Date	17	15	17	15	13	13	15	14	14
Time	16.00 ≀ 16.30	15.10 ≀ 15.35	16.30 ≀ 17.00	10.55 ≀ 11.30	13.30 ≀ 13.50	12.52 ≀ 13.15	11.35 ≀ 12.00	15.35 ≀ 16.20	9.30 ≀ 10.20
Weather	fine	fine	fine	fine	fine	fine	fine	fine	fine
Wind	W4	NW4	W4	NW4	NW4	NW4	NW4	0	E1
Wind wave*	4(1)	4(1)	4(2)	4(2)	4(1)	4(1)	4(4)	1(1)	1(1)
Swell*	2(0)	1(0)	2(0)	2(1)	2(0)	2(0)	2(2)	1(1)	2(1)
Water Colour	5	5	4.5	4	4	4	3	3	3
Transparency	6.5	6	11	14	12	12	15	16	22
Water temperature (surface) (°C)	20.38	21.50	21.12	22.32	21.44	21.44	22.78	22.92	22.92
〃 〃 (bottom) (°C)	22.60	22.00	21.96	22.40	22.44	22.44	22.78	22.76	22.82
Extension of the reef**	s	m	s	s	s	m	m	l	vl
Roughness of the reef**	s	s	m	s	m	m	m	l	m
Height of cliff in the reef (m)	<1	2–3	2–3	2–4	—	—	4–5	7–8	7–8
Thickness of mud-covering**	1	1	m	m	s	s	s	—	—
Height of the reef (m)	4–6	5–10	7	11	7	8–15	12	13–14	30

* Figures in parentheses are local conditions of diving stations.

** s, m and l reprents respectively small or smooth, middle and large or coarse.

Table 2. List of the main rock reef fishes and their abundance at each station.

Scientific Name	Japanese Name	Station A	B	C	D	E	F	G	H	I
Rudarius ercodes Jordan et Fowler	Amimehagi	+	±							
Mylio macrocephalus (Basilewsky)	Kurodai	+								
Girella punctata Gray	Mezina	+	+	+		+		+		
Pseudolabrui japonicus (Houttuyn)	Sasanohabera	+	+	+	+	+	±	+	+	+
Sebastiscus marmoratus (Cuvier et Valenciennes)	Kasago	+	+	+	+			+	+	+
Acanthurus variene Lesson	Kanranhagi	+	+	±	++	+		+	+	
Zanclus cornutus (Linné)	Tunodasi		±	+	+	+	+	+	+	+
Prionurus microlepidotus Lacépède	Nizadai		±	+	+	+	+	++	++	++
Chromis notatus (Temminck et Schlegel)	Suzumedai				+	+	++	++	+	+
Pomacentrus coelestis Jordan et Starks	Sorasuzumedai				++	++	++	++	+	++
Chaetodon collris Bloch	Tyōtyōuo				+	+	+	+	++	+
Stethojulis kalosoma (Bleeker)	Kaminaribera				+	+	±			+
Labridae sp. A	Bera sp. A				+	±			+	+
Acanthuridae sp. A	Nizadai sp. A				+	±		+	+	
Thalassoma cupido (Temminck et Schlegel)	Nisikibera				+	+		+	++	+
Leptoscarus japonicus (Cuvier et Valenciennes)	Budai				+			+	++	++
Parapristipoma trilineatum (Thunberg)	Isaki			++			++	++	++	++
Canthigaster rivulatus (Temminck et Schlegel)	Kitamakura						±	+	++	+
Epinephelus fario (Thunberg)	Nominokuti						±		±	+
Goniistius zonatus (Cuvier et Valenciennes)	Takanohadai						+	+	+	++
Oplegnathus fasciatus (Temminck et Schlegel)	Isidai						±	+	±	+
Epinephelus moara (Temminck et Schlegel)	Kue							±	±	+
Microcanthus strigatus (Cuvier et Valenciennes)	Kagokakidai							+	+	
Choerodon azurio (Jordan et Snyder)	Ira								++	
Plectorhynchus pictus (Thunberg)	Korodai								+	±
Goniistius zebra (Döderlein)	Migimaki								+	+
Pseudupeneus spilurus (Bleeker)	Okinahimezi								++	+
Callyodon ovifrons (Temminck et Schlegel)	Aobudai								++	++
Epinephelus chlorostigma (Cuvier et Valenciennes)	Hōsekihata									±
Lehtrinus choerorhynchus (Schneider)	Hamahuehuki									+

± frequent, + common, ++ abundant, ++ very abundant.

Table 3. Estimated body length by observation of the rocky reef fishes belonging to the middle class.

Fish	Body Length (cm)	Station A	B	C	D	E	F	G	H	I
Girella punctata Gray	10	+		+		+				
	15		+	+		+		+		
	20			+						
	30							+		
Sebastiscus marmoratus (Cuvier et Valenciennes)	10	+	+	+	+			+		+
	15								+	+
	above 20								+	+
Prionurus microlepidotus Lacépède	10		±	+	+		+	+	+	
	15				+	±		+	+	+
	20							+	+	+
	25								+	
Parapristipoma trilineatum (Thunberg)	10			++			++	++		
	15								++	++
	above 20									+
Epinephelus fario (Thunberg)	20									+
	25									+
	30						±		±	+
	40									+
Oplegnathus fasciatus (Temminck et Schlegel)	15						±		±	
	20							±		
	30							±		+
Ephinephelus moara (Temminck et Schlegel)	25								±	
	40							±		
	50									±
	60									±

± frequent, + common, ++ abundant, ++ very abundant.

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A STUDY ON THE PRODUCTIVITY OF THE TANABE BAY

(Part I)

VI. Zonal Arrangement of Intertidal Benthic Animals in the Tanabe Bay

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Intertidal animals show a remarkable vertical stratification, which is peculiar to the nature of the substrata. This paper deals with the result of a survey in the Tanabe Bay of such zonal arrangement in relation to the embayment degree.

Zonal arrangement of reef bottom animals

The survey of the reef fauna from the mouth of the bay to the islet of Hatake-zima, which limits the main bay from the inner bay, revealed that the zonal arrangement from the upper to the lower tidal level was in the sequence of *Littorina*-layer—*Chthamalus-Adula*-layer—*Saxostrea*-layer—*Tetraclita-Septifer*-layer (Tabs. 1~4). Of these layers, the last two are well defined on the reef facing the open sea, but in the inner bay *Septifer* becomes scarce and the demarcation between *Tetraclita*-layer and *Saxostrea*-layer becomes less conspicuous.

In *Littorina*-layer, there are several sublayers, which are arranged from the upper level in such a series as *Nodilittorina pyramidalis* sublayer —*N. granularis* sublayer—*N. picta* sublayer—*Littorina brevicula* sublayer—*Peasiella roepstorffiana* sublayer (Tab. 2). Of these sublayers, the last three or sometimes even the last four sublayers may overlap with *Chthamalus* layer which lie below *Littorina* layer.

In the inner bay east of Hatake-zima and near the mouths of baylets or indentations, some changes in the constituent species take place: 1) *N. pyramidalis*, *N. picta* and *P. roepstorffiana* disappear and only two species of *Littorina* group, i.e., *N. granularis* and *Littorina brevicula* are seen; 2) *Chthamalus-Adula* layer becomes *Chthamalus*-layer with some

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Table 1. Reef community of the intertidal zone at Tô-sima near the mouth of the Tanabe-Bay (number of animals per 25 cm²)

Station nos. (tidal level)	1 (upper)	2	3	4 (lower)
Nodilittoria granularis (Araretamakibi)	174	—	—	—
Peasiella roepstorffiana (Kobitourauzu)	—	4200	—	—
Chthamalus challengeri (Iwahuzitubo)	—	7900	8768	—
Adula atrata (Kuroguti)	—	4900	34	—
Saxostrea echinata (Kegaki)	—	—	—	22
Tetraclita squamosa (Kurohuzitubo)	—	—	1	7
Others	—	—	3	4

(Japanese names are given in parentheses)

Table 2. Reef community of the upper intertidal zone at Tô sima (number of animals per 50 cm²)

Station nos. (tidal level)	1 (upper)	2 (lower)
Nodilittorina pyramidalis (Ibotamakibi)	2	—
Nodilittorina granularis (Araretamakibi)	256	1
Littorina brevicula (Tamabiki)	1	11
Peasiella roepstorffiana (Kobitourauzu)	—	5
Others	—	2

Table 3. Reef community of the upper intertidal zone at the N-W end of Hatake-zima (n/50 cm²)

Station nos. (tidal level)	1 (upper)	2	3	4 (lower)
Nodilittorina granularis (Araretamakibi)	696	166	584	—
Littorina brevicula (Tamakibi)	—	10	72	—
Peasiella roepstorffiana (Kobitourauzu)	—	—	1752	4200
Adula atrata (Kuroguti)	—	—	120	4900
Chthamalus challengeri (Iwahuzitubo)	—	—	1452	7900

Table 4. Reef community in two places of the intertidal zone at the S–W part of Hatake-zima (n/50 cm²)

Station nos. (tidal level)	1 (upper)	2	3	4	5 (lower)	1 (upper)	2	3	4	5 (lower)
Nodilittoria granularis (Araretamakibi)	512	—	—	—	—	784	444	16	—	—
Chthamalus challengeri (Iwahuzitubo)	—	9308	32000	17280	—	48	4712	592	—	—
Adula atrata (Kuroguti)	—	—	10240	—	—	—	160	—	—	—
Tetraclita squamosa (Kurohuzitubo)	—	—	64	96	16	—	—	108	32	—
Saxostrea echinata (Kegaki)	—	—	—	240	448	—	—	612	448	—
Siphonaria japonica (Karamatugai)	—	—	—	—	64	—	—	16	—	—
Siphonaria sirius (Kikunohanagai)	—	—	—	—	—	—	—	32	48	16
Others	—	—	—	—	—	—	—	16	—	32

Table 5. Horizontal sequence of zonal arrangement of the reef community.

Intertidal zone	Strata	Species	Bay mouth	Central part	Inner bay
upper level	Littorina layer (Tamakibi)	Nodilittorina pyramidalis (Ibotamakibi)	→		
		N. granularis (Araretamakibi)	→	→	
		N. picta (Taiwantamakibi)	→		
		Littorina brevicula (Tamakibi)	←	→	←Littorina scabra (Uzuratamakibi)
		Peasiella roepstoffiana (Kobitourauzu)	→		
	Chthamalus-Adula layer (Iwahuzitubo-Kuroguti)	Chthamalus challengeri (Iwahuzitubo)	→	→	←Balanus amphitrite albicostatus (Sirosuzihuzitubo)
		Adula atrata (Kuroguti)	←	→	
		Saxostrea mordax (Ohagurogaki)	→		
	Saxostrea layer	Saxostrea echinata (Kegaki)	→	→	←Crassostrea gigas (Magaki)
	Tetraclita-Septifer layer (Kurohuzitubo, Murasaki-inko)	Tetraclita squamosa (Kurohuzitubo)	→	→	
lower level		Septifer virgatus (Murasaki-inko)	→		

Balanus amphitrite albicostatus; 3) *Saxostrea*-layer remains quite the same; and (4) *Tetraclita-Septifer*-layer disappears. In the further interior of the indentation, *Littorina*-layer is represented by *Littorina brevicula* only or with a small number of intermingled *Littoraria scabra*; *Chthmalalus*-layer if replaced completely by *B. amph. albicostatus* layer; and *Saxostrea* layer by *Crassostrea gigas* layer. The number of component species of the intertidal reef fauna becomes exceedingly small in the interior part of the bay. These features are shown schematically in Table 5.

Zonal Arrangement of Intertidal Animals on Sand and Mud

There are remarkable changes, both vertically and horizontally, in the constitution of intertidal fauna on sand-mud bottom of the Tanabe Bay.

Near the bay mouth there occur none of the on-fauna on sand-mud bottom. From four stations of shell-sand bottom with little mud, only two species, *Excirolana chiltoni japonica* and *Donacilla picta*, were collected, both of which belonged to active in-fauna (Table 6). On the bottom higher in the level than that of *Donacilla picta*, there occur *Ocypoda stimpsoni*, a crab living in a hole. On the sand-mud bottom in the inner bay, however, there occur some on-fauna or surface dwellers like *Batillaria multiformis*, and the thicket of *Zostera nana* is occupied by numerous species including *Pictocliton oualaniensis*, a snail living on the leaf. These facts make a contrast against the general tendency of the

Table 6. Vertical sequence of the intertidal benthic community of shell-sand bottom near the Seto Marine Biological Laboratory.

Stations nos. (tidal level)	1 (upper)	2	3	4 (lower)
Excirolana chiltoni japonica (Himesunahorimusi)	148	24	2	8
Donacilla picta (Tidorimasuho)	—	—	—	1

Table 7. Intertidal community on the sand bottom of Hatake-zima (n/50 cm²)

Station nos. (tidal level)	1 (upper)	2	3	4	5 (lower)	1 (upper)	2	3	4	5	6 (lower)
Atactodea striata (Isohamaguri)	5	4	4	8	—	5	6	1	5	7	1
Amygdala japonica (Asari)	—	—	—	—	—	—	—	—	—	2	—
others	—	—	—	—	1	—	—	—	—	—	—

decrease in the number of benthic species from the mouth to the interior of the bay.

In the central part of the bay, *Ocypoda stimpsoni* and *D. picta* are replaced by *Scopimera globosa* and *Atactodea striata*, and this zone is followed by *Batillaria multiformis* and *Amygdala japonica* zone, and then by *Zostera nana* zone with its peculiar animal community. In the innermost part of the bay, the upper level is occupied by *Ilyoplax pusillus*, *Cerithidea cingulata C. djadjariensis*, and the lower level is represented by *Zostera nana* community with *Cerithidea zonalis* and *Pictocliton oualaniensis* as dominants (Tab. 11), which is followed by *Zostera marina* community with *Macoma incongrua*, *Anadara troscheli* and *Contumax coradium*.

The community arrangement in the innermost part of the bay may be summarized as in Table 12.

Table 8. Gravel bottom community at the lower intertidal zone of Hatake-zima (n/50 cm²).

Station nos. (tidal level)	1 (upper)	2	3	4	5	6	7 (lower)
Batillaria multiformis (Uminina)	33	23	6	16	3	3	12
Amygdala japonica (Asari)	1	0	0	1	11	10	1

Table 9. Animal community of *Zostera nana* zone at the lowest intertidal zone of Hatake-zima (n/50 cm²).

Station nos. (tidal level)	1 (upper)	2	3	4 (lower)
Standella nicobarica (Yukigai)	—	3	4	1
Pillucina pisidium (Umenohana)	—	3	3	—
Proclava kochi (Kanimori)	—	—	1	—
Contumax dialeycum (Hosokôrogi)	—	19	259	—
Hinia festiva (Aramusiro)	—	1	—	—
Polychaeta spp.	10	30	10	11
Siphonosoma cumanense (Suzihosimusimodoki)	6	21	1	9
Alphaeus brevicristatus (Teppôebi)	2	5	—	—
Others	2	16	2	24

Table 10. Intertidal benthic community near the mouth of Hosono baylet (n/50 cm²).

Station nos. (tidal level)	1 (sand) (upper)	2 (sand)	3 (sand)	4 (Z. nana) (lower)
Baltillaria multiformis (Uminina)	4	1	—	—
Cerithidea cingulata (Henatari)	7	11	—	—
Cyclina sinensis (Okisizimi)	1	—	—	—
Pillucina pisidium (Umenohaha)	1	—	—	—
Batillaria zonalis (Ibouminina)	—	—	—	85
Umbonium moniliferum (Ibokisago)	—	—	—	186
Hinia festiva (Aramusiro)	—	—	—	9
Amygdala japonica (Asari)	—	—	—	2
Scopimera globosa (Kometukigani)	21	4	14	5
Others	—	1	19	22

Table 11. Intertidal benthic community in the inner part of Hosono baylet (n/50 cm²).

Stations nos. (tidal level)	Upper (mud)	Lower (Z. nana)
Cerithidea cingulata (Henatari)	254	29
Cerithidea djadjariensis (Kawaai)	17	16
Batillaria multiformis (Uminina)	4	—
Cyclina sinensis (Okisizimi)	1	—
Batillaria zonalis (Ibouminina)	—	10
Pictocliton oualaniensis (Himekanoko)	—	41
Arcopagia diaphana (Ityôsiratori)	—	3
Ilyoplax pusillus (Tigogani)	58	1
Macrophthalmus japonicus (Yamatoosagani)	—	2
Others	5	10

Table 12. Schematic representation of zonal distribution of the intertidal mud community in the innermost part of the Tanabe Bay.

Stations nos. (tidal level)	reed marsh (upper)	mud bottom	Zostera nana zone	Zostera marina zone (upper)
Assiminea castanea (Kuriirokawazansyo)	+			
Assiminea japonica Kawazansyo)	++			
Cerithidea rhizophorarum (Hutohenatari)	++			
Batillaria multiformis (Uminina)	+	+	++	
Cerithidea cingulata (Henatari)	+	++	++	++
Cyclina sinensis (Okisizimi)		++	++	
Anomalodiscus squamosus (Sioyagai)		+	++	
Cerithidea djadjariensis (Kawaai)	+	++	++	+
Batillaria zonalis (Ibouminina)			++	++
Arcopagia diaphana (Iyôsiratori)		++	++	++
Pictocliton oualaniensis (Himekanoko)			++	++
Pitar sulfurea (lôhamaguri)			+	
Macoma incongrua (Himesiratori)			+	+
Contumax coralium (Kogetunobue)			+	+
Brachidontes senhousia (Hototogisu)				++
Anadara troscheli (Himeakagai)				++

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A STUDY ON THE PRODUCTIVITY OF THE TANABE BAY (Part I)

VII. Horizontal Distribution of Intertidal Communities on Rocky Shores around the Tanabe Bay (Preliminary Report)[1]

By Huzio Utinomi

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Introduction

It is a general idea that the biological resources consist of fishery resources directly for fishery purposes and the surrounding biotic environments forming the "field" for their breeding and protection. Although a rough estimation of standing crop of natural resources may be obtained from catches of all fishing organisms of commercial importance year by year, it is essential to carry out a detailed synecological investigation on the regional distribution of all marine organisms in respective territories, regardless of commercial importance.

In this respect, the Tanabe Bay under consideration here is a good example of an embayment faced to open sea where is rich in biological resources, providing a good field for such an investigation. For the past several years the author has surveyed synecologically the distribution of main marine organisms forming prominent communities within the bay and its surrounding areas.

In this report, only the moderately large-sized sedentary animals and plants commonly and abundantly found on rocky shores are dealt with, since they are dominants of relatively stable communities and actually easy to be observed by everybody. However, as most of the northeastern coasts around the bay has not been as yet investigated, only a general scheme of the distribution of major intertidal communities in the Tanabe Bay is given here, deferring detailed descriptions of them to future papers which will be prepared after further detailed investigations.

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1 Studies on intertidal biocoenoses, No. 5.

Horizontal Distribution of Rocky-shore Sedentary Animals
(Fig. 1)

It will be seen from the foregoing Habe's account that a large number of littorinids, barnacles and rock oysters with different habitats occurring on rocky shores exhibit marked zonation, occupying different levels of tide range. The vertical extents of distribution of each species are apt to be influenced by various environmental factors such as inclination degree of substratum, degree of wave shock, altered salinity, light intensity, degree of desiccation, relative humidity, etc., so that they may vary considerably according to locations, correlated with any particular conditions.

Apart from these minor local variations, the distribution of major rocky-shore animal communities in general is evidently not uniform throughout the bay. Marked changes of distribution and components of the rocky fauna are correlated with the change of physical factors of the environments from the mouth of the bay, or the "open coast", to the interior of the bay, or the "protected coast", accompanied by the weakening of wave action, stagnation of sea water, lowered salinity due to estuarine waters or drainage, wave erosion of shore line followed by deposition of sediments and so on.

These transitional sequence of the hydrological and biological environments as a whole from the open sea to the bay may be expressed typologically as "strong, middle and weak degree of embaymental conditions" (after Miyadi et al, 1944), instead of the degree of exposure to the oceanic flood in the bay. In this respect, the intertidal biocoenoses are good indices of the embaymental character, not less than the benthic biocoenoses in the basin of bays. Generally, on exposed reefs on the open coast weak embaymental organisms are dominant, while in bays and estuaries or on semi-protected outer coast are strong embaymental organisms exceed the former.

Among the intertidal biocoenoses of rocky shores in the Tanabe Bay, the barnacle communities which are dominated by the following species occur in a descending series:

1. *Chthamalus pilsbryi* Hiro
2. *Chthamalus challengeri* Hoek
3. *Balanus amphitrite albicostatus* Pilsbry
4. *Tetraclita squamosa japonica* Pilsbry
5. *Balanus tintinnabulum volcano* Pilsbry

Of these, Chthamalus pilsbryi of the highest level and *Balanus tintinnabulum volcano* of the lowest level are of weak embayment in nature

and found only on the surf-swept reefs around the islets and promontories in the mouth of the bay, though the latter alone may extend to the northwest end of Hatake-zima, an islet in the bay.

In the mouth of the bay, *Chthamalus challengeri* and *Tetraclita squamosa japonica* (another subspecies *viridis* too, though in small number) are found predominantly in the upper and lower parts of mid-tidal zone respectively. These two species further penetrate within the bay, but in the inner part they are restricted to the seaward edge of capes and usually occur in association. The estuarine barnacle, *Balanus amphitrite albicostatus,* on the other hand, is dominant along the protected coast of the inner-most baylets, but even on the rocky coast near the mouth it locally occurs in patches, being found only in semi-protected places at higher levels than the *Chthamalus* zone.

Turning to the molluscan assemblages, *Septifer virgatus* (Wiegmann) (weak embayment degree), *Saxostrea mordax* (Gould) (weak embayment degree), *Hormomya mutabilis* (Gould) (middle embayment degree) and *Saxostrea echinata* (Quoy et Gaimard) (middle-strong embayment degree) are the most conspicuous as sedentary bivalve communities. Of these, the first *Septifer virgatus,* as well as *Mytilus crassitesta* Lischke often found together encrusting the *Balanus tintinabulum-Tetraclita squamosa* association, is important as indicator species of surf-swept open coast. Inside the bay they are replaced by protected-water forms such as *Hormomya mutabilis,* though locally on capes or submerged slopes only.

Saxostrea echinata and also a small-sized mytilid *Adula? atrata* (Lischke) are widely distributed all throughout the bay, showing a wider range of telerance to varying environmental conditions. Even in the inner-most area of the bay where no barnacle exists, they are found on all the stony beach areas, and thus they may be marked as an indicator species of strong embayment degree.

Beside these, the distribution patterns of several species of littorinids in the Tanabe Bay are also important in discussing the transition of intertidal faunas from the open sea to the inner bay. The details are, however, here omitted, as one may refer to the foregoing report made by Habe.

Horizontal Distribution of Rocky-shore Marine Algae

(Fig. 2)

Reference to the ecological distribution of algal communities and their intertidal zonation in this country is very scarce. The algal communities are not persistent throughout the year in contrast to the animal

communities. Although the survey was not finished owing to the limitation to winter and spring seasons here, the data on distribution are rather fragmental. Here is, therefore, given only an outline of the major algal communities (exclusive of the Cyanophyta) as indicators widely distributed on the rocky shores in the Tanabe Bay.

In the mouth of the bay exposed to open sea, the following three zones are recognized in all on rocky shores from high tide levels downwards.

1. *Gloiopeltis furcata* Postels et Ruprecht
   G. complanata (Harvey) Yamada
2. *Porphyra suborbiculata* Kjellman
   P. dentata Kjellman
3. *Sargassum thunbergi* (Mertens) O. Kuntze
   Hijikia fusiforme (Harvey) Okamura

Just below the lowest tide level, vegetations of *Pterocladia tenuis* (Rhodophyta), *Ecklonia kurome* Okamura, *Eckloniopsis radicosa* (Kjellman) Okamura, *Sargassum patens* C. Agardh, *Padina arborescens* Holmes (Phaeophyta), etc. which are subject to regular immersion at spring tides, are found commonly. Here there is much greater variety in the algal communities.

These algae occur fairly commonly in distinct zones on the open coast, showing a weak embayment degree in habitats. The two species of *Gloiopeltis* at the highest level are widespread on all the open coast outside the bay, but within the bay confined to the seaward side of capes at the same level. *Porphyra* also shows a similar distribution, but its prosperous appearance is only temporary (usually late in March here).

At the lower levels, *Sargassum thunbergi* and *Hijikia fusiforme*, usually mixed together, form an almost complete cover over the rocks. The former occurs in wider vertical and horizontal range than the latter which is restricted only to the seaward surf-swept rocky cliffs. This may be explained from the relative tolerance to surf exhibited by these fucoids. Namely, the latter alga (*Hijikia*) can withstand greater intensity of wave shock and dessication structurally, being often found around the exposed edges of shallow rock pools, while absent on permanently submerged faces of pools. Whereas *Sargassum thunbergi* like other *Sargassum*-species is more hydrophilous for existence and it is therefore found also in subtidal zone not exposed even at high spring tides. Entering toward the quiet bay, they become disappear and they are replaced by a brown alga *Scytosiphon lomentarius* (Lyngbye) J. Agardh at the same level.

At the high tide level, on the other hand, a widespread green alga

Monostroma nitidum Wittrock is luxuriant during early spring on all coasts in the innermost region of the bay, but on the outer exposed coast it is found locally, i. e. in sheltered localities protected from strong surf or on the landward highest zone separated widely by a reef flat. In the innermost area, another green alga *Enteromorpha linza* (Linné) J. Agardh is represented only as occasional where sewage flows out.

One of peculiar algae forming a large consociation on rocky shores, additionally important as indicators, is a warmlwater form *Boodlea coacta* (Dickie) Murray et De Toni, though not so ubiquitous as the above-mentioned algae. This green alga occurs in the form of compact mattress on flat-topped rock surface at higher levels on the exposed rocky shore. *Ulva conglobata* Kjellman, too, is found in patches here and there, but prefers more wetness to exposure in sheltered areas. More interesting is the fact that *Ulva conglobata* communities occasionally cover over the dense growth of the above-mentioned bivalve *Hormomya mutabilis*, which occurs abundantly on exposed rocks, especially near the outlets of hot-spring water. However, this association is not always a universal feature. It is probable that the existence of both species is favoured by relatively wetted condition provided with constant flow of water during exposure.

Correlation between Animal and Algal Communities

Whenever they occur zonally in the intertidal zone, certain animal and algal communities occupy approximately the same levels as habitats, and thus the correlation between them at the same level is seemingly very intimate. Although their direct relation to tide levels is generally unsuitable, as has been repeatedly emphasized by T. A. Stephenson and co-workers, it will be seen that, generally speaking, there is a fair degree of similarity between the intertidal zonation of animal and algal communities. Such a zonal arrangement in aquatic habitats may account for the relative tolerance by themselves to different climatic and physiographic factors, so that animal and algal communities often overlap one another at roughly equivalent levels everywhere. In other words, all biotic communities established on the same habitat at similar levels and showed a similar physiographic stability, though quite different as to component species, seem to belong to the same biome-type. Otherwise, the direct dealings between animals and plants in respect to these association or co-existence cannot be explained properly at present.

Comparing Figs. 1 and 2, the correlation between major intertidal communities related to tide levels in the Tanabe Bay may be summarized as follows:

	Tide levels	Dominant animals	Dominant algae
1)	Upper tidal zone	*Chthamalus (pilsbryi, challengeri)*	*Gloiopeltis (furcata, complanata)*
2)	Mid-tidal zone	*Balanus amphitrite albicostatus* + *Saxostrea echinata*	*Monostroma nitidum* + *Enteromorpha linza*
3)	Lower tidal zone	*Tetraclita squamosa (japonica, viridis)*	*Sargassum thunbergi*
4)	Infratidal fringe	*Balanus tintinnabulum volcano* + *Septifer virgatus*	*Hijikia fusiforme*

1, 3 and 4 .... exposed shore; 2 .... protected shore.

As far as the intertidal communities are concerned, high-level communities penetrate more deeply into the sheltered innermost waters of the bay than do low-level communities. The horizontal distribution of the intertidal biota is more complex than that of benthic fauna of the subtidal zone and affected to a greater extent by bay topography and water movement. So the scheme of embayment degree, a discussion mainly based on the benthic communities in the bottom of bays, is not here taken as applicable just it is. In the intertidal area, a sequence of communities is not necessarily arranged in continuous parallel zones, and there are many instances that even species of strong embayment degree may occur as patches in topographically sheltered localities on the exposed coast where open-sea forms are dominant.

Summary

A general account is given of the horizontal distribution of main intertidal biotic communities on all the rocky coasts around the Tanabe Bay in relation to the intertidal zonation. Three major biological regions are recognized, basing on the horizontal distribution.

1. Outer region. Open shore forms are most prevalent along the coast, west of the boundary line of Bansyo-no-hana—Nada-sima—Okino-iso, inclusive.

2. Middle region. East of the preceding region and west of the boundary line of Sakata-hana—Hatake-zima—Kasima—Kagura-zima—southern end of Mera Cape. This is a transition area from inside to outside the bay, with a mixture of open shore and protected shore forms. On seaward edge of rocky reefs there are formed *Tetraclita*-dominated communities characteristic to open shores like the mouth of the bay.

3. Inner region. This region, east of the preceding boundary line, is i quiet bay water area along which plain rocky reefs with sand or

shingle deposits are developed. Pure inner bay or estuarine forms are predominant, but some semi-exposed shore forms may be found only at ends of capes.

Fig. 1. Chart showing the distribution of main indicator species of intertidal rocky shore animals in the Tanabe Bay.

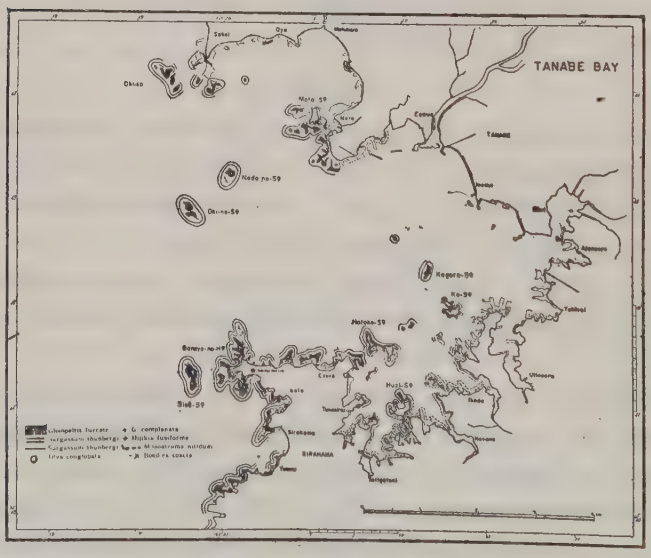

Fig. 2. Chart showing the distribution of main indicator species of intertidal rocky shore algae in the Tanabe Bay.

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THE OCEAN WAVES AND THE SECONDARY UNDULATIONS OF TIDES ON THE SOUTHERN COAST OF KII PENINSULA

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§1. Introduction.

Among the various kinds of water waves which affect coastal engineering and other maritime industries, the tides have been rather fully investigated,but the actual state of wind waves and swell has not yet been made clear owing to difficulties in observation. Concerning the secondary undulations of tides many excellent papers have been published since the appearance of the famous paper of K. Honda, T. Terada and others[1], but these papers for the most part concern the period of undulation, and there are only few that consider the amplitude or energy of oscillation which is directly related to the destructive power of the waves. The present report gives some statistics on wind waves, swell and secondary undulations of tides on the southern coast of Kii Peninsula, based on observations made over a long period of time.

§2. Data.

The sources of data on wind waves and swell are the "Monthly Reports of Coastal Oceanographical Observations (Engan Kaiyô Geppô)" published by the Central Meteorological Observatory for the years 1951-1956 for Sionomisaki and for the years 1951-1954 for Owase. These give the results of visual observations made (according to the wave scale shown in Table 1) at Sionomisaki Weather Station and Owase Weather Station once daily at 10^h a.m.

The sources of data on secondary undulations of tides are the "Monthly Summaries of Tidal Observations (Kentyô Gaihô)" published by the Central Meteorological Observatory for the years 1936-1956 for Kusimoto times of beginning and end, the mean periods and the maximum ranges and for the years 1953-1956 for Uragami and Owase. These give the of conspicuous secondary undulations read off from the mareograms at the tidal stations of Kusimoto, Uragami and Owase.

The localities of the stations are shown in Fig. 1. The mean wind at Sionomisaki, which is an extract from Reference (2), is given in Table 2.

§3. Wind waves and swell.

Tables 4, 5 and 6 show, respectively, the frequency distribution of the mean wave height, and the maximum of the wave scale number observed, for each month for wind waves at Sionomisaki. The mean wave height was obtained by making the assumption that each wind wave takes the value of the wave height at the middle of the corresponding number of the wave scale.

Table 4, 5 and 6 show, respectively, the frequency distribution of directions of wind waves, the mean periods of wind waves and swell in each month, and the frequency distribution of periods of wind waves and swell at sionomisaki. The mean height of wind waves at Sionomisaki is about 1.5 m, and if we compare this value with those in other regions shown in Reference (3), we can see that this district is one of the regions of Japan where waves are especially high.

As would be naturally expected, waves are generally high in the typhoon season from July till October. (In September, the mean wave height is rather small, but the number of high waves is large.) This can be seen also in the observed maximum of the wind wave scale number shown in Table 3. Judging from the mean wind velocity, the wind is rather stronger in winter, but wind waves are not so high owing to the fact that the direction of wind is northerly (blowing offshore). Moreover, as seen in Table 4, the most frequent directions of wind waves are E and W, and do not necessarily coincide with the direction of wind shown in Table 2. This seems to be due to the effect of ocean bottom topography. Waves with periods of 6-8 seconds account for 85% of the total number of observations.

The height, direction and period of swell at Sionomisaki are given in Tables 6-9. The days on which the height of swell is less than 2 m and those on which it is equal to 2-4 m account for about 48% and 49%, respectively, of the total number of days of the year, while those on which it exceeds 4 m account for only 3.5% or 13 days. And one half of these conspicuous swells occur in the typhoon season from August to October. Besides, as seen from Table 8, the swells with longer periods as well as with higher wave heights occur most frequently in July and August, probably due to long swells ("doyônami") coming from distant typhoons south of Japan. The most frequent periods of swell are 9-13 sec. and are rather larger than those of wind waves. The directions of swell are, as seen from Table 9, mostly southerly.

At Owase, since the observing point is situated inside a bay, swells are scarcely observed; wind waves are also small. As seen in Table 10 99% of all the wind waves observed are those with wave height less than 1 m; the mean wave height is 0.2 m at most; and the maximum of the wind wave scale number observed is only 6.

§4. Secondary undulations of tides.

Table 11 shows the frequency distributions of the periods of the secondary undulations observed at Kusimoto, Uragami and Owase. According to K. Honda, T. Terada and others, at Kusimoto secondary undulations with periods of 11.6-13.0, 16.5-18.6 and 21.5-23.7 min. frequently occur, the first two corresponding to the oscillations of bay water having nodes at AB and CD, respectively, in Fig. 2.

Now, let l be the length of the bay and h the depth, then the period of the secondary undulation is given by

$$T=\frac{4}{2k+1}\int_0^l \frac{dx}{\sqrt{gh}}, \qquad k=0,\ 1, 2, \ldots\ldots,$$

or, if h be the mean depth of the bay, we have

$$T=\frac{4l}{(2k+1)\sqrt{gh}}.$$

The "calculated period" of secondary undulation for Kusimoto shown in Table 12 is that of the fundamental oscillation ($k=0$) obtained by K. Honda and others by using the above formula and applying a "mouth correction", and this agrees closely with the observations.

According to our data (Table 11), at Kusimoto secondary undulations with periods of 12-13 min. occur most frequently, but the frequency distribution shows a fairly wide dispersion. This seems to show that the nodal lines of the undulation are not so well defined as AB and CD in Fig. 2, but fluctuate fairly widely in position.

At Uragami, the most frequent period is 12-13 min., with a period of 24-25 min. second. Judging from the result of calculations shown in Table 12, these periods correspond to the undulations with nodal lines at EF and GH, respectively, in Fig. 3.

At Owase, a period of 20-21 min. is most frequently observed, and that of 14-15 min. next. In this case, as seen from Fig. 4, the shape of the bay is so irregular and complex that it is not easy to determine the modes of oscillation which correspond to the above-mentioned periods, but judging from the result of calculations given in Table 12, we may suppose tentatively modes of oscillation having nodal lines at KL and IJ, respectively.

If we obtain the frequency distributions of wave heights (double amplitudes) of the secondary undulations occurring in respective bays, we have the result as shown in Table 13. It is natural that the smaller the wave height the higher becomes the chance of occurrence, but personal error is likely to affect the reading of very small wave heights from the record chart; thus, cases may occur in which a wave may be read off by one person, and rejected by an other. Therefore in the present case wave heights less than 20 cm in the case of Kusimoto and Uragami and those less than 10 cm in the case of Owase have been rejected. Hence it must be borne in mind that if these secondary undulations of smaller wave height be taken into account, the values of percentage shown in Table 13 will be somewhat altered.

The average annual number of occurrences of secondary undulations with wave height more than 20 cm is 22 for Kusimoto, 6 for Owase and 2 for Uragami. At Kusimoto the number of occurrences of conspicuous undulations is far larger than at the other two stations, and this seems to be closely connected with the orientation of the bay to the open sea as well as to its size and form.

Moreover, the wave height of secondary undulations differs very much for different places even in the same bay, but in the present case the stations under consideration were all situated near the end of each bay farthest from the sea. Therefore the above results may be regarded as representing the susceptibility of each bay to secondary undulations.

In regard to the seasonal change of secondary undulations, it is said that at Kusimoto and Uragami conspicuous undulations occur most frequently from November till March, and decidedly less in summer (Table 14). This seems to be due to the fact that in winter the number of depressions passing through this area is large, and also there is a strong NW monsoon; though for detailed conclusions a further investigation is necessary.

For Owase no definite conclusion can be given owing to scarcity of data, but conspicuous undulations seem to occur most frequently in the typhoon season as well as in winter.

The three occurrences of biggest secondary undulations at each station is given in Table 15. The range of the biggest is 143 cm at Kusimoto, 88 cm at Uragami, and 60 cm at Owase; all these were caused by typhoons. At any rate, especially large secondary undulations appear most frequently in the case of developed typhoons which passed near the station, and those due to other causes such as ordinary depressions, fronts, tunamis, etc. are rather few. Of course, in the case of record-breaking large tunamis, secondary undulations with wave heights far larger than those mentioned

above would have occurred, but they are few and far between.

Lastly, the duration of conspicuous secondary undulations at each station is given in Table 16. Duration of less than 24 hr represent about 80% of the total number at Kusimoto, about 70% at Uragami, and about 75% at Owase. Sometimes the conspicuous undulations last for two or three days.

§5. Concluding remarks.

Some statistical investigations based on all available data were made on wind waves and swell as well as the secondary undulations of tides on the southern coast of Kii Peninsula, and the results were collected in sixteen tables. Further investigations may show their dependence on meteorological conditions, etc., but here we can only report the results of statistics. We should be happy if this report is of some service to parties concerned in planning or executing coastal works in this district.

In conclusion, the authors wish to express their hearty thanks to the Japanese National Commission for UNESCO for financial aid.

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Table 1. Wave scale

Scale	0	1	2	3	4	5	6	7	8	9
Wind wave (wave height, in m.)	0	0~0.5	0.5~1	1~2	2~3	3~4	4~6	6~9	9~14	14<
Swell (wave height, in m.)	0	0~2	0~2	2~4	2~4	2~4	4<	4<	4<	Confused
Swell (wave length, in m.)	—	0~200	200<	0~100	100~200	200<	0~100	100~200	200<	—

Table 2. Wind at Sionomisaki (after T. Okada's "The Climate of Japan.")

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual mean
Mean wind direction	N48W	N49W	N73W	S13W	S43E	S47E	S14W	S31E	S72E	N67E	N11E	N52W	--
Mean wind speed (in m/sec)	5.0	4.8	4.8	4.5	4.2	4.3	4.0	4.5	4.2	4.2	4.1	4.7	4.4

Table 3. Frequency distribution (%) of wave height, the mean wave height (in metres), and the maximum of the wave scale number observed for wind waves at Sionomisaki.

Month		1	2	3	4	5	6	7	8	9	10	11	12	Mean
Frequency distribution of wave heights(%)	0～1m	46	45	58	43	45	47	41	38	60	42	43	47	46
	1～2m	23	25	21	30	26	24	27	33	15	26	33	25	26
	2～4m	26	23	18	22	26	26	29	24	20	27	22	24	24
	4～6m	4	5	3	4	3	2	2	2	3	2	2	3	3
	6～	1	2	0	1	0	1	1	3	2	3	0	1	1
Total		100	100	100	100	100	100	100	100	100	100	100	100	100
Mean wave height (in m.)		1.57	1.64	1.30	1.56	1.58	1.53	1.63	1.74	1.39	1.72	1.44	1.56	1.56
Maximum of the wind wave scale number observed		7	8	6	7	6	7	7	8	8	9	6	7	—

Table 4. Frequency distribution (%) of directions of wind waves at Sionomisaki.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Mean
N	1	6	3	1	3	0	1	1	2	2	2	10	3
NE	12	13	13	24	17	9	11	12	7	28	23	10	15
E	10	9	13	17	28	25	25	22	39	23	18	11	20
SE	2	7	12	6	13	11	12	14	11	12	6	5	9
S	2	6	7	9	7	3	8	8	5	4	4	2	5
SW	7	10	17	17	9	21	21	21	19	11	9	9	14
W	27	22	20	18	18	29	21	20	15	17	20	26	21
NW	39	27	15	8	5	2	1	2	2	3	18	27	13
Total	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 5. Mean periods (in sec.) of wind waves and swell at Sionomisaki.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Wind waves	6.8	6.8	7.3	7.3	7.1	7.3	6.9	7.0	7.1	7.1	6.9	6.8	7.0
Swell	10.2	10.3	11.7	11.3	10.6	11.3	11.5	13.1	9.5	11.3	10.0	10.8	11.0

Table 6. Frequency distribution (%) of periods of wind waves and swell at Sionomisaki.

Period (in sec.)	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total	Mean (in sec.)
Wind waves	0	5	30	32	23	7	2	1	0	—	—	—	—	—	—	—	100	7.0
Swell	—	—	1	3	8	10	17	17	17	15	7	3	1	1	0	0	100	11.0

Table 7. Frequency distribution (%) of heights of swell at Sionomisaki.

Month		1	2	3	4	5	6	7	8	9	10	11	12	Mean
Frequencey (%) of wave heights	0～2m	54	58	55	48	44	39	33	38	57	44	42	59	47.6
	2～4m	45	40	43	50	53	58	65	55	33	50	55	39	48.9
	4～	1	2	2	2	3	3	2	7	10	6	3	2	3.5
Total		100	100	100	100	100	100	100	100	100	100	100	100	100.0

Table 8. Frequency distribution (percentage to the total number of observations in each month) of periods of swell with wave height more than 2m. at Sionomisaki.

Month		1	2	3	4	5	6	7	8	9	10	11	12	Mean
Period (in sec.)	8.0> (0～100)*	24	24	18	29	20	32	28	29	17	25	25	19	24.2
	8.1～11.3 (100～200)*	18	9	19	16	28	21	27	23	19	27	24	18	20.7
	11.4< (200～)*	4	9	8	7	8	8	12	10	7	4	9	4	7.5
Total		46	42	45	52	56	61	67	62	43	56	58	41	52.4

* The numerals within ( ) show the wave lengths (in metres) as of deep water waves.

Table 9. Frequency distribution (%) of directions of swell at Sionomisaki.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Mean
N	0	0	0	0	1	0	0	0	0	0	0	0	0
NE	1	1	1	1	0	0	1	0	2	3	1	0	1
E	3	1	3	1	5	1	3	2	15	9	6	3	4
SE	14	19	22	28	39	21	33	31	30	40	33	27	28
S	31	38	41	51	36	45	42	40	32	30	34	30	37
SW	42	34	25	14	17	30	20	26	18	16	18	27	24
W	8	7	8	5	2	3	1	1	3	1	6	10	5
NW	1	0	0	0	0	0	0	0	0	1	2	3	1
Total	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 10. Wind waves at Owase.

Percentage of the number of occurrence of various wave heights					Total	Mean wave height (in m.)	Maximum of the wind wave scale number observed
0～1m	1～2m	2～4m	4～6m	6m<			
98.7	1.0	0.2	0.1	0.0	100.0	0.2	6

Table 11. Frequency distributions (%) of the periods of the secondary undulations at Kusimoto, Uragami and Owase.

Period (in min.)	Kusimoto	Uragami	Owase
4, 5	1.2	—	3.8
6, 7	1.2	—	—
8, 9	3.2	1.5	—
10, 11	9.1	4.6	—
12, 13	34.1	64.6	—
14, 15	18.8	4.6	15.5
16, 17	10.3	—	3.8
18, 19	7.6	1.5	7.7
20, 21	7.4	4.6	27.0
22, 23	5.3	3.2	3.8
24, 25	0.9	9.2	7.7
26, 27	0.6	6.2	3.8
28, 29	0.3	—	—
30, 31	—	—	7.7
32, 33	—	—	—
34, 35	—	—	7.7
36, 37	—	—	—
38, 39	—	—	3.8
40, 41	—	—	7.7
Total	100.0	100.0	100.0

Table 12. Calculated and observed values of the prevalent periods of the secondary undulations at Kusimoto, Uragami and Owase.

Locality	Kusimoto (Fig. 2)		Uragami (Fig. 3)		Owase (Fig. 4)	
Position of the nodal line	$\overline{AB}$	$\overline{CD}$	$\overline{EF}$	$\overline{GH}$	$\overline{IJ}$	$\overline{KL}$
Length of the bay, l (in km.)	1.3	3.4	1.6	3.3	3.7	5.9
Depth of the bay, h (in m.)	5.0	15.4	7	8	24	35
Calculated period (in min.)*	12.8	18.3	12.8	24.7	16.1	21.3
Observed period (1)	12, 13	—	12, 13	24, 25	14, 15	20, 21
Observed period (2)	11.6～13.0	16.5～18.6	—	—	—	—

* In the case of Kusimoto, the "mouth correction" has been made, while in the case of Uragami and Owase, it has not been made.

The "observed period (1)" is based upon our data, and the "observed period (2)" on Reference (1).

Table 13. Frequency distributions (%) of ranges (double amplitudes) of the secondary undulations at Kusimoto, Uragami and Owase.

Range (in cm)	Kusimoto	Uragami	Owase
10>	—	—	—
10～	—	88.3	—
20～	39.0	6.7	40.0
30～	32.5	0.0	45.0
40～	16.7	0.0	5.0
50～	5.3	3.3	5.0
60～	2.8	0.0	5.0
70～	1.0	0.0	0.0
80～	1.2	1.7	0.0
90～	0.0	0.0	0.0
100～	0.3	0.0	0.0
110～	0.3	0.0	0.0
120～	0.6	0.0	0.0
130～	0.0	0.0	0.0
140～	0.3	0.0	0.0
150～	0.0	0.0	0.0
Total	100.0	100.0	100.0

Table 14. Mean number of occurrences of conspicuous secondary undulations at Kusimoto, Uragami and Owase.

Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual total
Kusimoto (above 20cm)	2.4	2.4	2.8	1.5	1.4	1.3	0.5	0.6	1.2	1.7	3.0	2.7	21.5
Uragami (above 10cm)	2.8	2.0	1.3	0.8	0.5	1.5	0.3	0.8	1.0	1.5	2.3	1.3	16.1
Owase (above 20cm)	0.7	0.7	0.7	0.5	0.5	0.3	0.0	0.3	0.7	1.0	0.5	0.0	5.9

Table 16. Frequency distributions (%) of durations of conspicuous secondary undulations at Kusimoto, Uragami and Owase.

Duration (in hr.)	Kusimoto	Uragami	Owase
0～	32	29	15
6～	29	29	20
12～	15	5	30
18～	7	8	10
24～	5	10	10
30～	4	2	5
36～	3	3	5
42～	1	7	0
48～	1	0	0
54～	1	2	0
60～	1	0	5
66～	0	2	0
72～	1	3	0
Total	100	100	100

Table 15. The three occurrences of biggest secondary undulations at respective stations of Kusimoto, Uragami and Owase.

Locality	Beginning				End		Duration (in hr.)	Period (in sec.)	Range (in cm.)	Cause
	Year	Month	Day	Hour	Day	Hour				
Kusimoto	1952	11	5	7	8	7	72	12	143	Typhoon AGNES, No. 5220
	1952	2	18	8	19	16	32	20	125	Front
	1953	9	24	7	25	22	39	2	122	Typhoon TESS, No. 5313
Uragami	1953	9	25	0	25	24	24	13	88	Typhoon TESS, No. 5313
	1953	11	26	4	26	22	18	13	51	Tunami caused by earthquake off Bôsô Peninsula
	1954	9	17	3	18	23	44	15	50	Typhoon LORNA, No. 5414
Owase	1954	9	17	8	18	23	39	20	60	Typhoon LORNA, No. 5414
	1953	9	25	10	—	—	—	4	56	Typhoon TESS, No. 5313
	1955	11	21	8	21	21	13	16	43	Low (travelled eastward along the Pacific coast.)

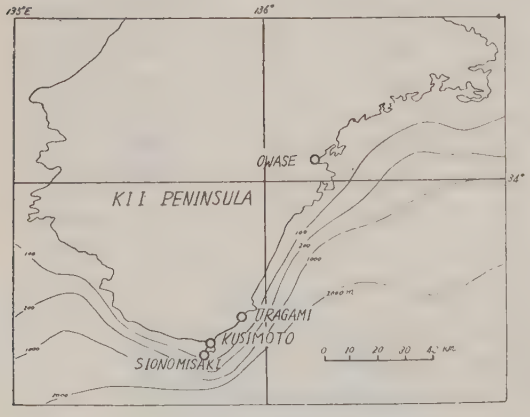

Fig. 1. Map of Kii Peninsula.

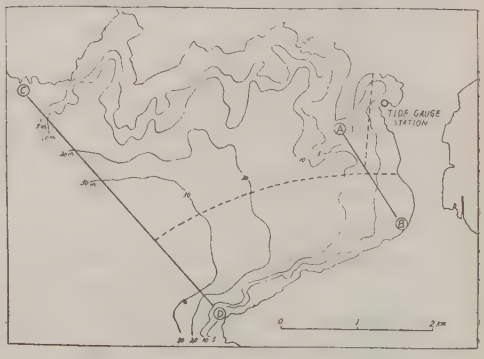

Fig. 2. Kusimoto and its neighbourhood.

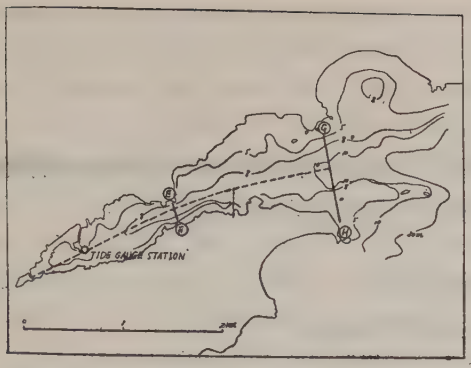

Fig. 3. Uragami and its neighbourhood.

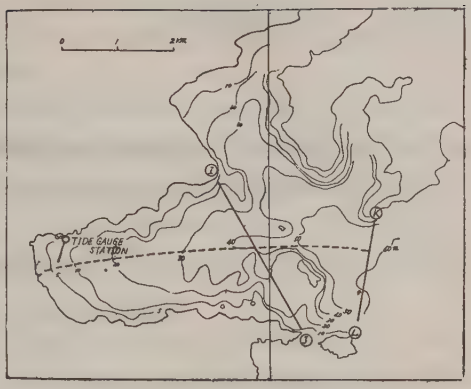

Fig. 4. Owase and its neighbourhood.

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A NOTE ON THE HYDROGRAPHICAL CONDITIONS OF KUROSIWO AND ITS NORTHERN BOUNDERY IN 1956

By Michitaka Uda
(Tokyo University of Fisheries)

I *Result of Survey during Late July-Early Aug. 1956, in the North-Eastern Sea-Region of Japan. (By Shinyō-Maru, Training Boat belonging to the Tokyo University of Fisheries).* Following the preceding year we have carried out the oceanographic observation through the polar frontal zone in the NE Sea-region of Japan down to the 1000 m. depth for 15 observing stations during from late July to early Aug. 1956 (see Tab. 1), and especially have studied of the fluctuation of the intermediate water belonging to the Oyasiwo Under-Current which has been inferred to influence on the Kurosiwo Sea-region off Kii-Penninsula and to have some intimate relation to the anomalous sea conditions in this region. (Accordingly we have made some oceanographical observations off Kumano Nada in winter and in the following summer.) In this paper the author wishes to state his hearty thanks for the cooperation made by the captain (Mr. Keizirō Ozawa), officers and crew of Shinyō-Maru (236 ton, 450 HP), with Mr. Hisayasu Ōtubo.

In the following, the results of our observation are summarized:

(1) Plotting the profiles of water temperature, salinity, dissolved oxygen, phosphate (Fig. 1-4) and comparing to the result of preceding year by our boat (see Records of Oceanographic Works in Japan Sp. No. Mar. 1957. PP. 1-20, M. Uda, Y. Morita, M. Ishino: Results from the Oceanographic Observations in the North Pacific (1955-56) with Umitaka-Maru and Shinyō-Maru.), we have remarked the prosperity of the cold current and the decay of warm current (Kurosiwo and Tugaru Warm Current) in the whole observed layers of the North Eastern Sea of Japan in the summer of 1956, and the conspicuous southerly shift of polar frontal zone (Oyasiwo Front) compared to the preceding year.

During the early summer (about June) of this year, we have recognized a remarkable meander of Kurosiwo Front where in the margin of unwelling waters of cyclonic eddies (denoting water temperature 18°-19°C) along the Kurosiwo Front very rich albacore fishing-grounds presented

the historical abundant record of its catch.* Succeedingly during the summer of 1956 the cold current kept its prosperity and surpressed the north-going warm current toward south.

(8) Since in the summer the vertical gradient of water temperature off the coast of the NE region (Sanriku) of Japan was very remarkable and the frontal zone of the prosperous cold current developed highly, a note-worthy rich catch of the bluefin tuna fishing by purse-seine boats in this sea-region (waters off Kinkazan—off Kamaisi—NE off Hatinoe) during July-Oct. has been produced.

By our observation, for example, the difference of the water temperature and salinity of sea water between the two stations 8 (38°-15'N 141°-51'E) and 10 (38°-29'N 142°-05'E) crossing the frontal zone are shown in Table 1,

Such as the values of 10.7°C and more than 0.7‰ at the depths of 50 m. and 100 m.,

Against St. 9 in the cold eddy corresponding to the upwelling zone at the head of cold current on the Oyasiwo Front, near St. 8 shows the saline water of about 34‰ belonging to the Kurosiwo Mixed Water corresponding to the anticyclonic warm eddy in this upper layer.

We found some remarkable bands of current-rips ("Siome") on the sea-surface near this frontal zone i.e. At about 5:00-6:30 a.m. 30, July, near St. 8. (E/N 24 sea-miles off Kinkazan) on the both sides of "Siome" made of drifting dusts and bubbles we have seen a sharp line of demarkation between the warm (20°C) and clear water (color of the sea 3-4 in Forel's scale) and the cold (16.2°C) and turbid water (color of the sea 5-6) where shoals of porpoises and marlins were swimming and on the side of cold water thin steam-fog evaporated from sea surface.

Also at St. 7 (142°-00.8'E. 37°49.3'N) we observed a fish-shoal made of young bluefin-tunas and skipjacks. At St. 6 (52 sea-mile east off Kinkazan) we have found again the swimming porpoises and marlins along the "Siwome" between the warm (higher than 20°C) and clear water (color of sea 3) and the cold and turbid water (19°C, color 5-7), and about thirty fishing-boats of purse-seine nets operating their fishing. In short we recognized clearly the existence of the boundary of water masses belonging to the cold and warm currents and of the favourable tuna-fishing grounds developed there.

(3) Between St. 12. and St. 13. we have noted another frontal zone i.e. the boundary between the warm and saline water belonging to Tugaru Warm Current (a branch of Tusima Current) in the Japan Sea flown out

* In early summer of 1957 a more abundant catch of albacore has been noted.

through Tugaru Strait) and the cold water with relatively low salinity belonging to Oyasiwo Cold Current. (see Table 2).

In this sea-region on the side of Tugaru Warm current during summer and fall seasons of this year a very favourable fishing grounds of bluefin-tuna (feeding on the shoals of sardine, pacific saury and mackerel etc.) off Hatinoe were developed after the long interval of ten-several years.

(4) The southerly development of the dichothermal water seems to be remarkable than that of the preceding year which shows the stronger intensity of Oyasiwo Under-Current than that of the preceding year. The depths of the temperature-minimum (dichothermal) layer and of the salinity minimum (intermediate water) layer coincide almost well in each other. Or, in detail the dichothermal waters of the water temperature less than 2°C were observed in 1956 (this year) at 37°50'-39°30'N. (at depths ranging from 75 to 400 m.) south off Kusiro compared to the preceding year (1955) of the locations at 39°0'-41°21'N. (at depths ranging from 50 m to 500 m depths). Moreover, the intermediate water (salinity minimum less than 33.5 ‰) southerly proceeded to the latitude of 38°30'N in this year (1956) against to the preceding year showing the corresponding distribution north to 39°00'N. At the 200 m. depth between st. 9. and 12. the value of dissolved oxygen shows the rich distribution showing 6-7$^{cc}/_{l}$, in particular at the 25 m. depth of St. 9. 7.65$^{cc}/_{l}$. Therefore we may also prove the southerly shift of polar front in the summer of 1956 in comparison to that in the same season of the preceding year (1955) on the basis of the distribution of dissolved oxygen.

(5) In the lower layer near the polar front the state of the upwelling of the saline deep water up to the 600 m. depth are seen into the intermediate (salimity-minimum) layer.

(6) The relatively warm (higher than 3°C) and relatively saline (34.1-34.2‰) mesothermal water appears to be particularly notable in the lower layer of the 400-600 m. depths between St. 10 and St. 12 (lying between 39°11'N and 40°33'N).

(7) Concluding the above, we have recognized the development of cold current since the year of 1955 in the lower layer of the North-eastern sea-region of Japan with some what remarkable, recently appeared anomalous meander of Kurosiwo around the abnormally upwelled cold water mass off Kumano Nada. (See in the above cited paper by M. Uda, Y. Morita, M. Ishino (1956) pp. 18-20.)

II. Note on the oceanographic observation in Kurosiwo Area made by Shinyō Maru. in winter (middle March) of 1957. The author with Dr. Yasukazu Saitō and Mr. Sadami Kadota on board of Shinyō-Maru carried out the Oceanographic Observation of Kurosiwo area

in the waters within several tens sea-miles from the coast (Tateyama-Kumano Nada-Siwo no Misaki). However, unfortunately due to the violent westerly monsoon has blown day by day during our cruise we have not the expected result and observed only 8 stations down to the 800 m. depths. The rough results show us some what warmer water temperature than that of the same season (winter) in 1956, but remarkably colder compared to the normal year except in the Sagami Bay where warm oceanic (Kurosiwo) water invades near the coast and consequently it is interesting to us to inspect the fishing conditions of yellow-tail set-net fishery, showing the poor catch in the colder Kumano Nada, Ensyū Nada and Suruga Bay with the contrast to the unusual rich catch in the warmer Sagami Bay.

(The results of our Observation in detail with the full data shall be published later).

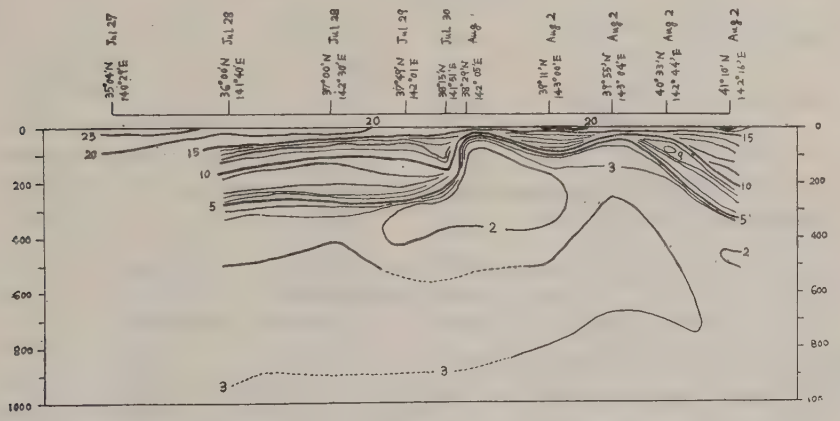

Fig. 1. Temperature Profile Off Katuura to Off Siriya Shin'yō-Maru July-August 1956.

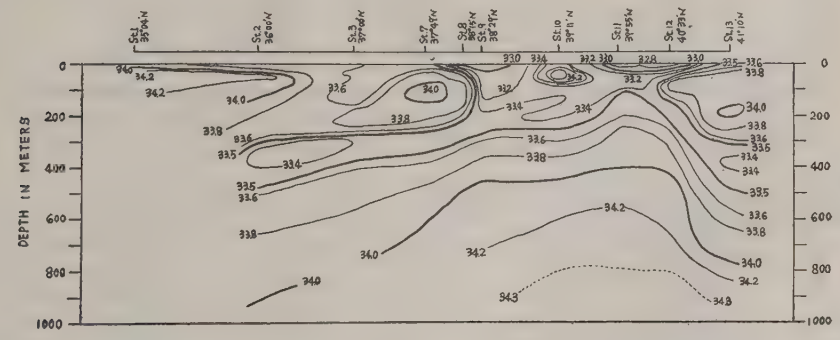

Fig. 2. Salinity (‰) Profile. Off Katuura To off Siriya Shin'yō-Maru 27, July—2, August 1956

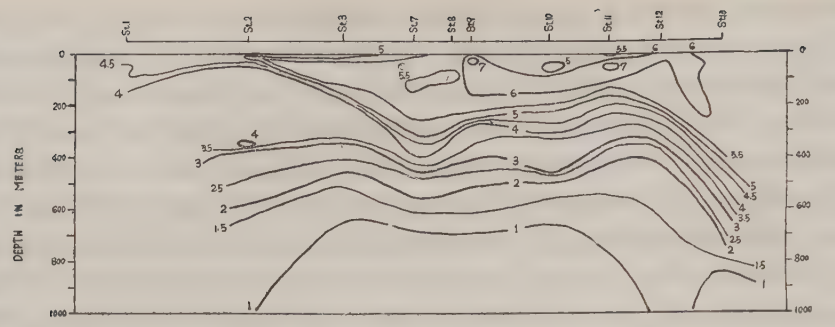

Fig. 3. Dissolved O_2(ml/L) Profile Off Katuura to Off Siriya, Shin'yō-Maru shin'yō-Maru, July—August 1956

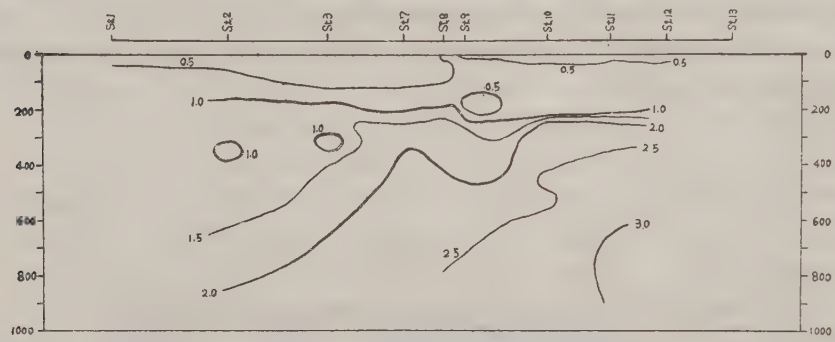

Fig. 4. Phosphate-P (μg atoms/L) Profile Off Katuura to Off Siriya Shin'yō-Maru July—August 1956

Table 1. An Example of Observed Front off Kinkazan.
(Aug. 1. 1956, Shinyō-Maru)
St. 8 (38°-15′N. 141°-15′E), St. 9 (38°-29′N. 142°-05′E)

Observed Layer	Water Temp (°C)			S (‰)		
	St. 8	St. 9	Dif.	St. 8	St. 9	Dif.
0m	17.26	18.35	− 1.09	32.97	32.85	+0.12
10	15.84	14.55	+ 1.29	33.22	32.76	+0.48
25	14.26	5.71	+ 8.55	33.37	32.97	+0.40
50	13.19	2.54	+10.65	33.78	33.06	+0.72
75	12.54	2.03	+10.51	33.77	33.17	+0.60
100	12.32	1.55	+10.77	33.93	33.15	+0.78
150	10.47	1.41	+ 9.06	33.96	33.28	+0.68
200	6.12	1.68	+ 4.44	33.62	33.44	+0.18

Table 2. Boundary (front) of Water-masses belonging to Tugaru Warm Current and Oyasio Cold Current. (Aug. 2. 1956. Shinyō Maru).
St. 13 (41°-09.8′N, 142°-15.5′E), St. 12 (40°-33′N, 142°-44′E)

Observed Layer	Water Temp. (°C)			S (‰)		
	St. 13	St. 12	Dif.	St. 13	St. 12	Dif.
0m	18.03	16.98	+1.05	33.53	32.74	+0.79
10	17.78	15.50	+2.28	33.51	32.85	+0.66
25	15.19	13.13	+2.06	33.69	33.33	+0.36
50	14.17	8.36	+5.81	33.89	33.17	+0.72
74	13.81	9.50	+4.31	33.98	33.77	+0.21
98	12.34	8.40	+3.94	33.89	33.82	+0.07
146	11.20	5.07	+6.13	33.92	33.59	+0.33
195	10.93	2.91	+8.02	34.04	33.50	+0.54
288	6.26	2.23	+4.03	33.62	33.68	−0.06

Table 3. Kurosio-Oyasio Survey. July 27- Aug. 3. 1956.
Shinyō-Maru, Tokyo Univ. of Fisheries.
(Captain K. Ozawa)

St. 1. off Katuura, Bottom Depth 170 m. (18 h 06 m), 120 m (19 h 05 m). by Echo Sonnding.

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	27.50	18.79	33.95	4.51	21.79	—
10	26.67	18.79	33.95	4.63	22.05	—
25	24.78	18.86	34.07	4.76	22.73	—
50	21.55	18.98	34.29	4.45	23.83	—
72	20.01	18.93	34.20	4.53	24.16	—
93	16.67	18.93	34.20	4.09	24.99	0.60

Plankton net haul (0–100 m). (19.40 19.42) BT-test 1.

Date 1956-7-27.
Time 18.06-17.00.
Long. 140°-28.0′E (Beginning.)
Lat. 35°-02.6′N
↓
Long. 140°-29.5′E (End.)
Lat. 35°-05.8′N
Color of sea. 2.
Transparency 25 m.
Pressure 1013. 2MB.
wind ESE 6 m/sec.
Cloud Ci-Cs 2-3.
Weather bc. Airtemp-
Swell. (6-7 sec).
Current, NNE 2. 6 Kn.

St. 2. E. off Tyōsi, Bottom Depth 2150 m. (echo)

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	24.46	18.63	33.66	4.88	22.51	trace
10	23.28	18.64	33.68	5.26	22.89	trace
25	18.53	18.79	33.95	4.87	24.35	0.10
50	16.13	18.93	34.20	4.00	25.11	0.40
75	13.46	18.90	34.15	3.75	25.65	0.95
100	11.86	18.85	34.05	3.86	25.90	1.00
142	10.60	18.81	33.98	3.55	26.09	0.85
191	8.77	18.72	33.82	3.78	26.27	1.40
266	6.44	18.64	33.68	3.80	26.48	1.95
354	2.56	18.43	33.30	4.17	26.59	0.85
443	2.82	18.53	33.48	2.84	26.61	1.05
530	3.12	18.60	33.60	2.07	26.78	1.20
705	3.23	18.72	33.82	1.08	26.94	1.55
900	3.02	18.81	33.98	1.01	27.10	2.20

Date 1956-7-28.
Time 03.16-05.55.
Long. 141°-41.5′E (Begin.)
Lat. 36°-00.0′N
↓
Long. 141°-38.2′E (End.)
Lat. 36°-06.5′N
Color of Sea 3-4.
Transparency (16 m)→13 m.
Pressure-wind 0.
Weather b.
Cloud 0. Swell 1.
Current N (fairly strong.)

BT-test 2. 4 h 46 m Sun rise
Plankton net 0-150 m (5.57)
(30 cm. dia.)
06.13 Several young flying fishes seen.

St. 3. 91°, 63 SM. off C. Sioya. Bottom Depth 2700 m.

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	24.93	18.73	33.84	4.86	22.50	trace
10	23.39	18.66	33.71	4.77	22.85	trace
25	17.26	18.42	33.29	5.62	24.15	0.10
50	12.96	18.60	33.60	5.62	25.33	0.35
72	11.26	18.57	33.55	5.74	25.61	—
94	10.28	18.57	33.55	5.52	25.80	0.35
142	8.85	18.56	33.53	5.44	26.01	0.65
188	8.87	18.73	33.84	3.06	26.25	1.15
237	7.99	18.76	33.89	3.18	26.42	1.45
316	3.29	18.49	33.40	3.72	26.61	0.75
395	2.70	18.54	33.50	3.62	26.73	1.20
316	3.22	18.62	33.64	2.29	26.80	1.75
554	3.11	18.70	33.78	1.32	26.92	1.55
692	3.15	18.76	33.89	0.98	27.01	2.00

μg atoms/L

Date 1956-7-28.
Time 1200-14.30.
Long. 142°-29.8′E (Begin.)
Lat. 36°-58.2′N
↓
Long. 142°-31.0′E (End.)
Lat. 37°-00.0′N
Colorof Sea 3.
Transparency 22 m.
Cloud. O. Weather. b.
Airtemp. 27.5°C
Wave. 1-2. Swell. 2.
Current. NE.

BT.-test. 3. About 15.00 2 marlins, Porpoises Seen, many birds, drifting substances seen.

St. 4. 94 sm SE/E off Kinkazan. Bottom Depth over 3000 m. (echo.)

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	24.80	18.65	33.69	4.78	22.45	trace
10	20.74	18.80	33.96	5.19	23.80	0.35
25	16.93	18.99	34.31	4.06	25.02	0.35
50	15.02	18.96	34.25	3.81	25.42	0.75
72	14.13	18.93	34.20	3.73	25.56	0.55
97	12.88	18.88	34.11	3.50	25.78	0.90
141	10.60	18.84	34.04	3.14	26.11	0.85
194	8.39	18.76	33.89	2.94	26.36	0.90
268	6.65	18.74	33.86	2.75	26.60	0.85
357	3.31	18.54	33.50	2.98	26.68	1.75
445	3.90	18.64	33.68	1.95	26.77	2.00
564	3.59	18.72	33.82	1.44	26.91	2.25
752	3.04	18.78	33.93	1.61	27.05	2.10
940	2.87	18.83	34.02	0.95	27.15	2.25

Date 1956-7-28.
Time 19.30-21.15.
Long. 143°-13.5′E
Lat. 37°-36.6′N (Begin.)
↓
Long. 143°-20.5′E
Lat. 37°-37.8′N (End.)
Pressure, 10 14.8 mb.
Wind. SW. 5 m/s
Cloud. Cs. Weather b.
Airtemp. 25.7°C
Visibility. 8.
Wave 2.3. Swell 1.

BT. No. 4. (18 h)
5 (18.30) 6 (20.50)

Plankton Net (Open Net)
0-150m, Shipdrift E/N 3.5kt.

St. 5. Kinkazan East 105′

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	21.76	18.70	33.78	4.74	23.39	trace
10	21.54	18.67	33.73	—	23.40	0.30
25	19.55	18.71	33.80	4.87	23.97	0.15
50	15.81	18.94	34.22	—	25.21	0.80
73	13.01	18.83	34.02	—	25.65	0.90
97	9.96	18.70	33.78	—	26.03	0.40
146	7.37	18.61	33.62	3.56	26.30	0.85
195	5.68	18.55	33.51	—	26.44	1.00
264	3.90	18.54	33.50	3.98	26.62	1.10
352	3.80	18.63	33.66	2.52	26.76	1.30
440	3.76	18.70	33.78	1.91	26.86	1.62
582	3.83	18.76	33.89	1.44	26.94	2.00
774	—	18.84	34.04	1.06	—	2.30
970	2.90	18.86	34.07	1.05	27.18	2.10

Date 1956-7-29.
Time 03.10-04.10.
Long. 143°-49′E
Lat. 38°-25.5′N
Color of the Sea 2-3.
Transparency 26 m.
Cloud O-Ci-As 0-3.
Weather b. Air Temp 23.5°C
Wave 1. Swell 1.
Bt. No. 7. 04.40

Plankton Net haul 0-150 m.

St. 6. 104°, 52 SM off Kinkazan, Bottom Depth 1400 m.

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	20.68	18.43	33.30	4.86	23.30	0.40
10	17.01	18.46	33.35	5.73	24.26	0.60
25	12.28	18.76	33.89	5.52	25.69	0.75
50	11.34	18.77	33.91	5.52	25.88	0.80
74	10.53	18.77	33.91	5.39	26.02	1.00
97	10.10	18.82	34.00	5.42	26.18	1.00
146	9.11	18.80	33.96	5.66	26.31	—
197	8.21	18.79	33.95	5.69	26.43	—
255	4.78	18.61	33.62	5.72	26.62	1.05
340	2.25	18.61	33.62	4.30	26.87	1.50
425	2.89	18.82	34.00	1.86	27.12	1.60
448	2.92	18.82	34.00	1.91	27.12	1.90
597	3.20	18.93	34.20	1.07	27.25	2.30
746	3.18	19.01	34.34	0.85	27.37	—

Plankton net haul 0-150 m.

Date 1956-7-29.
Time 11.00-12.40.
Long. 142°-49′E
Lat. 38°-08.5′N (Begin.)
↓
Long. 142°-52.0′E
Lat. 38°-13.5′N (End.)
Color of the Sea 4.
Transparency 19 m.
Cloud Cs 9.
Weather C.
Airtemp. 24.0°C.
Wave 2-3, Swell 2.

BT. No 8.
About 30 Purse-seine boats, porpoises, marlins(2), flocks of birds seen.
At the front of the colder turbid water (color of sea 5-7, T<19°C) and warmer (T>20°C), and clear (color of sea 3) water, light fog.

St. 7. Bottom Depth 530 m.

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	18.99	18.56	33.53	5.16	23.91	0.55
10	15.51	18.59	33.59	5.64	24.79	0.05
25	13.34	18.67	33.73	5.91	25.36	0.10
50	11.90	18.75	33.87	5.92	25.75	0.15
74	11.07	18.81	33.98	5.55	25.99	0.40
99	10.18	18.86	34.07	5.51	26.21	0.30
149	9.21	—	—	5.21	—	0.80
198	8.19	18.77	33.91	5.55	29.40	—
297	2.00	18.50	33.42	5.25	26.73	1.75
396	1.93	18.60	33.60	4.10	26.88	2.45
495	2.56	18.76	33.89	2.27	27.06	2.25

Date 1956-7-20.
Time 19.00-20.30.
Long. 142°-00.8′E
Lat. 37°-49.3′N
Pressure 10 13.3 mb.
Wind S 4 m/s
Cloud O. Weather b.
Air temp. 21.5°C
Wave 2. Swell 1.

BT. No 9.
17.45-19.30 Shoals of young bluefintuna and skipjack with flocks of birds. Angled.
19.20. Cb. Lightning.
At night, shoal of young squid, pacific saury.

Plankton Net haul 0-150 m.

St. 8. 24 SM. E/N. off Kinkazan.

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	17.26	18.25	32.97	5.78	23.91	0.05
10	15.84	18.39	33.22	5.86	24.45	0.80
25	14.26	18.47	33.37	5.73	24.87	0.35
50	13.19	18.70	33.78	5.50	25.45	0.40
74	12.54	18.69	33.77	5.40	25.54	0.40
97	12.32	18.78	33.93	5.35	25.70	0.30
145	10.47	18.80	33.96	5.51	26.08	0.90
194	6.12	18.61	33.62	5.68	26.47	1.00

Date 1956-7-30.
Time 08.00-08.40.
Long. 141°-51.3′E
Lat. 38°-15.5′N (Begin.)
↓
Long. 141°-51.6′E
Lat. 38°-14.7′N (End.)
Color of the sea 4.
Transparency 21 m.
Pressure 1012.8 mb.
Wind WNW 1 m/s
Cloud Ac 8.
Weather c (f)
Air Temp 20.6°C
Visibility 6.
Wave 1. Swell 1.
Current S/E 1.35 kt.

Plankton net haul 0-150 m.
BT. No. 10, 5.00-6.30. "Siome" (bubbles, dusts)
(Temp. 20.8°C, color of sea 3-4)→(T. 16.2°C, color 5-6).
School of porpoise, flock of sea birds, fog over cold water surface.

St. 9. N 69°E. 23 SM off Kinkazan.

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	18.35	18.18	32.85	5.98	23.55	0.05
10	14.55	18.13	32.76	6.82	24.35	0.40
25	5.71	18.25	32.97	7.65	26.00	0.60
50	2.54	18.30	33.06	6.58	26.40	0.70
75	2.03	18.36	33.17	6.55	26.52	0.40
100	1.55	18.35	33.15	6.42	26.55	0.60
150	1.41	18.42	33.28	6.23	26.66	0.50
200	1.68	18.51	33.44	5.04	26.76	0.30
295	1.87	18.60	33.60	3.94	26.89	1.60
394	2.14	18.72	33.82	3.03	27.03	1.55
492	2.74	18.90	34.15	2.00	27.25	2.15

Date 1956-8-1.
Time 19.00-20.30
Long. 142°-05′E
Lat. 38°-29′N
Color of the sea (5).
Transparency (17.5), m.
Pressure 1011.8 mb.
Cloud Cu 4. Weather f.
Air temp 22.5°C
Wave o. Swell 1.
Visibility 6.
Current ENE.

BT. No. 11.
18.45 sun-set.
19.50 shoal of small squids.
(length 10-12 cm)

Plankton net haul 0-150 m.

St. 10. 57.5 SM. off Kamaisi.

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	22.05	18.52	33.46	5.34	23.06	trace
10	18.48	18.95	34.24	5.47	24.59	0.05
25	14.69	18.94	34.22	5.39	25.46	0.45
50	12.22	18.95	34.24	4.55	25.98	0.60
74	10.44	18.88	34.11	4.88	26.20	0.30
98	4.21	18.46	33.35	6.46	26.47	0.85
144	3.14	18.50	33.42	6.07	26.64	0.70
192	1.16	18.47	33.37	5.73	26.75	0.55
258	1.35	18.51	33.44	4.91	26.78	2.10
344	1.89	18.69	33.77	3.26	27.01	2.10
430	2.16	18.81	33.98	3.24	27.13	2.55
535	3.00	18.87	34.09	1.52	27.19	2.45
715	3.10	18.95	34.24	0.83	27.29	2.75
890	2.81	19.02	34.36	0.71	27.41	2.75

Date 1956-8-2.
Time 03.00-05.15.
Long. 142°-59′E
Lat. 39°-10′N (Begin.)
↓
Long. 143°-01′E
Lat. 39°-13′N (End.)
Color of the sea 4.
Transparency 20 m.
Pressure 1012.8 mb.
Wind NNE 4 m/s.
Cloud Ac. Sc 9. Weather C.
Air temp 22.2°C.
Visibility 5.
Wave 1-2. Swell 2.

BT. No. 12.
03.24-Twilight
0430-Sunrise
Purse-seine boats 5 seen.

Plankton net haul (04.00) 0-150 m.

St. 11. N 70°E 52.5 SM. off Miyako. Bottom Depth 1350 m.

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	19.11	18.09	32.68	5.57	23.25	0.00
10	18.50	18.12	32.47	5.51	23.42	0.05
25	8.13	18.28	33.03	6.60	25.72	0.50
50	4.37	18.44	33.31	7.07	26.44	0.75
72	3.67	18.44	33.31	6.44	26.50	0.95
95	3.56	18.47	33.37	6.41	26.55	0.90
142	3.55	18.58	33.57	5.25	26.71	0.60
189	2.16	18.59	33.59	4.54	26.75	0.55
279	3.95	18.75	33.87	3.61	26.91	2.35
372	3.50	18.80	33.96	2.34	27.03	2.50
465	3.43	18.90	34.15	1.55	27.18	2.80
578	3.30	18.93	34.20	1.36	27.23	2.80
723	2.68	18.95	34.26	1.06	27.23	3.20
905	2.70	19.03	34.38	0.86	27.43	3.00

Date 1956-8-2.
Time 10.05-12.35.
Long. 143°-04′E
Lat. 39°-55′N
Color of the sea 4.
Transparency 15 m.
Cloud Sc 10.
Weather c.
Air temp. 21.0°C.
Wave 3. Swell 1.

BT. No. 13.
Plankton net haul 0-150 m. rich copepoda (macro), (Calanus finmarchicus) with some larvae.

St. 12. E 54 SM. off Hatinoe C. Same, Bottom Depth 1580 m.

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	16.98	18.12	32.74	6.07	23.80	0.05
10	15.50	18.18	32.85	6.28	24.22	0.05
25	13.13	18.45	33.33	6.25	25.09	0.10
50	8.36	18.36	33.17	6.58	25.80	0.75
74	9.50	18.69	33.77	5.83	26.09	0.80
97	8.40	18.72	33.82	5.77	26.30	0.65
145	5.07	18.59	33.59	5.84	26.57	—
194	2.91	18.54	33.50	5.50	26.72	—
228	2.23	18.64	33.68	3.96	26.91	—
385	2.69	18.78	33.93	2.44	27.08	—
483	3.00	18.87	34.09	1.53	27.19	—
580	3.01	18.91	34.16	1.60	27.23	—
774	2.78	18.97	34.27	1.40	27.35	—
964	2.70	19.02	34.36	1.12	27.42	

Date 1956-8-2.
Time 17.05-18.40.
Long. 142°-44′E
Lat. 40°-33′N
Color of the sea 5.
Transparency 7 m.
Cloud S, Sc 10.
Weather c.f.
Air temp 17.4°C.
Wave 4. Swell 1.
Wave height 1-1.5 m.
Wave length 7-10 m.
Period 3 S.
Wave vel. 3 m/s.

BT. No. 14.
Plaukton net haul 0-150 m.
(Calanus, mysis, diatom)

St. 13. S 59°E 38 SM. off C. Siriya. Bottom depth 1100 m.

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	18.03	18.56	33.53	5.47	24.15	—
10	17.78	18.55	33.51	5.50	24.17	—
25	15.19	18.65	33.69	5.98	24.95	—
50	14.17	18.76	33.89	5.61	25.30	—
74	13.81	18.81	33.98	5.59	25.44	—
98	12.34	18.76	33.89	5.65	25.78	—
147	11.20	18.78	33.92	5.67	25.93	—
195	10.93	18.84	34.04	5.71	26.07	—
287	6.26	18.61	33.62	5.90	26.45	—
392	2.14	18.48	33.39	5.77	26.70	—
478	1.78	18.53	33.48	4.41	26.80	—
521	2.02	18.56	33.53	4.06	26.82	—
694	2.36	18.71	33.80	2.52	27.00	—
868	2.92	18.93	34.20	0.90	27.28	—

Date 1956-8-2.
Time 23.00-01.10.
Long. 142°-15.5′E
Lat. 41°-09.8′N
Cloud Sc 10.
Weather C.
Air temp 17.5°C.
Wave 4. Swell 1.

BT. No. 15.
23.20. under elec, lamp small pacific saury 2. (length about 10 cm), squid 1 (length 20 cm) sampled by tow-net.

Plankton net 0-150 m.
(rich diatoms)

St. 14. S 30°E 26.4 SM. off C. Siriya, Bottom depth 650 m.

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	18.28	18.59	33.59	5.51	24.13	—
10	16.96	18.68	33.75	5.71	24.57	—
25	15.84	18.76	33.89	5.94	24.95	—
50	15.34	18.84	34.04	5.43	25.18	—
73	15.00	18.84	34.04	5.51	25.25	—
95	12.98	18.80	33.96	5.54	25.61	—
142	11.24	18.81	33.98	5.69	25.96	—
190	4.33	18.50	33.42	6.27	26.52	—
297	1.37	18.50	33.42	5.21	26.77	—
396	2.86	18.59	33.57	4.02	26.77	—
495	2.38	18.69	33.77	2.49	26.97	—

Date 1956-8-3.
Time 03.00-04.35.
Long. 141°-50.0′E
Lat. 41°-04.0′N
Color of the sea 6.
Transparency 11 m.
Weather f.
Air temp 18.3°C.
Wave 2-3.

BT. No. 16.
Under elec. lamp small squids sampled. fog.

Plankton net haul 0-150 m.
(Phyto-plankton, rich)
light yellowish.

St. 15. Tugaru Strait. Bottom depth 320 m.

Depth	T° C	Cl ‰	S ‰	O_2ml/L	σ_t	Phosphate-P μg-atoms s/L
0m	19.30	18.77	33.91	5.30	24.13	0.05
10	19.02	18.79	33.95	5.37	24.22	0.05
25	18.09	18.85	34.05	5.33	24.55	0.10
50	15.50	18.99	34.31	5.43	25.35	0.05
74	15.20	19.03	34.38	5.40	25.47	0.20
93	14.80	19.03	34.38	5.31	25.56	0.30
138	13.08	18.86	34.07	5.71	25.69	0.25
184	7.73	18.69	33.77	5.52	26.36	0.50
230	3.67	—	—	5.32	—	0.70

Date 1956-8-3.
Time 07.30-08.10.
Long. 141°-24.3′E
Lat. 41°-32.0′N
Color of the sea 5.
Transparency 9 m.
Cloud Sc 10.
Weather c.
Air temp 18.4°C.
Wave 3.
Current NNW.

BT. No. 17.
(Phyto-pl. very rich)
brownish tint.

Plankton net haul (0-150 m.)

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ON THE "SHIOME" AT THE BOUNDARY ZONE OF THE KUROSHIO AND THE COASTAL WATERS OFF SHIONOMISAKI

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Abstract—The velocity and surface temperature at the northern boundary of the Kuroshio off Shionomisaki were observed by GEK and a sensitive recording thermometer and it was found that the position of abrupt change of velocity and temperature are not same and both shows a stepwise change.

§1. Introduction—About the water mass and seasonal variation of Kuroshio, several things have been known from the many observations and studies. However, in most cases, the data of currents were not obtained by direct measurements but by the dynamic computations before the GEK came into being used. We prepared GEK and a sensitive recording thermometer (thermister) with the aim of studying the structure of Kuroshio.

The observations were carried out from 16 to 20 December, 1956 and in February, 1957, by patrol ship "KUMANO" under the command of Tanabe Maritime Safety Base and research vessel "KAIYO" belonging to Hydrographic Office.

§2. Equipments—The GEK used in this observation, was assembled in our Hydrographic Office but without any particular construction. The thermister-thermometer was planned and framed with the exclusive purpose of our observations. Since surface temperature-change in the open ocean is no more than 4°~5°C even in the Shiome of the Kuroshio where the greatest horizontal temperature gradient seems to exist, it is necessary for us to have the thermometer as sensitive as possible to observe the Shiome which is changeable and complicated. We adopted as the recorder the electronic auto-balancing mili-volt meter (which is the same type as attached to the GEK), and 1.5mV (1.5cm on the recording paper) corresponds to 1.0°C. The full-scale of the meter is 12mV (corresponds to 8°C) and we can switch to various temperature band. It was regrettable that we could not have BT work fully but a few times on account of the fact that the winch was of manual-type.

§3. The distribution of surface temperature and velocity on the

Shiome*—Fig. 1, 2 and 3 show the cruise pattern, the surface temperature and the currents in December respectively. The contradictory values in the distributions (especially in the current chart) show the daily change of current.

3-1. Observation on the 16th, Dec. Fig. 4 (a), (b) show the changes of temperature and current observed on the 16th, Dec. when we traversed the Shiome. Fig. 4 (a) and (b) correspond to the cruise (a) and (b) in Fig. 1 respectively. Fig. 4 (a) shows us the existence of several narrow (0.2-0.5 mile wide) Shiome's (of temperature), in each of which the temperature rises stair-casely with the difference of 0.5°-0.8°C up to more than 20°C in the main current zone of the Kuroshio where temperature comes to be limited to almost constant. We can also see that the zones (5-6 miles wide) between these stair-cases are nearly homogeneous and mixed waters. Moreover, we can see that the 0.5 kt spring zones in current towards 10^h-15^m and 10^h-50^m corresponding to those in temperature. However, the most remarkable spring in current towards 11^h-40^m corresponds to the little decrease in temperature.

Fig. 4 (b) shows the Shiome east of Shionomisaki contrasting with Fig. 4 (a) of the west side. In (b), compared with in (a), the both gradients of temperature and velocity are great and the structures are simple (especially so in velocity). The overlapping of (a) with (b) tells us the coincidence of the Shiome at 10^h-50^m in (a) and bending at 15^h-08^m in (b). This fact seems to infer us that the water south of Shiome at 10^h-50^m in (a) flows out as the Kuroshio to the east of Shionomisaki.

3-2. Observation on 19th, Dec. Fig. 4 (c), (d) and (e) show the structure of the Shiome east of Shionomisaki. From these figures, we can see (c) and (d) have the same feature. It is characteristic, that the temperature decreases gradually at first from the southern high temperature zone and then lowers down in two steps and that the temperatures of the high temperature zone and of the middle steps in (c) equal to ones in (d).

As to velocity, the distribution in (d) shows the typical one which the velocity increases gradually from the south to the maximum in just front of the Shiome and then it decreases abruptly and it lowers down stair-casely in the Shiome. Compared the velocity with the temperature, at the maximum velocity of current the temperature has already begun to decrease and the Shiome of current are generally shifted to the north of

* The current velocities in Fig. 4, 7 and Fig. 8, which were obtained from the continuous records of G.E.K. show the current-components perpendicular to the courses of vessel. So the variations in current direction were not taken into account.

the Shiome of temperature. The above-mentioned middle step in the temperature distribution corresponds to the first step in the velocity distribction.

The results of observation in (e) are somewhat different from in (c) and (d). The highest temperatures are coincident in both cases but the area of temperature corresponding to the middle step mentioned in (d) is far wider than in (e) and the low temperature part which is conspicuous in (c) or (d) is scattered in (e). Similarly, the features of velocity distribution are almost same in the great velocity region (though the absolute value of velocity is smaller by about 0.5 kt), but the decrease of velocity in the small velocity zone in (e) are more gradual than in (c) or (d). This difference between (e) and other two cases, in spite of the fact that the distance between (e) and (d) is nearly equal to that between (c) and (d) is rather interesting though we cannot now explain the reason.

We carried out B.T. observations at three stations in (e). Fig 5 and 6 show the record of the observations and the vertical section of temperature drawn from B.T. traces. At the farthest southern B.T. station (No. 4), the homogeneous upper water (21°C) reaches to the depth of 20 m and below it there is a frontal layer which shows 1.5°C decrease in 20 m depth. No. 5 B.T. station is placed at the end of the Shiome and there appears no distinct spring layer. B.T. No. 6 is carried out at the farthest northern part and there are two frontal layers at the depths of 40 m and 60 m respectively.

Of these observation stations, the change of temperature of the frontal layer at B.T. No. 4 coincides with the change of surface temperature at the Shiome. From this fact, we can compute the declination of discontinuous frontal layer as about 20′. According to Defant,

$$\delta = -\frac{1}{gc}\,\frac{\rho v - \rho' v'}{\rho - \rho'}$$

where δ is the declination of frontal layer, g is the acceleration of gravity, ρ and ρ' are the densities of water masses and ρ is greater than ρ', c is $\frac{1}{2\omega \sin\varphi}$, v and v' are uniform velocities of lower and upper layer. If we suppose $v'=200$ cm/sec and $v=100$ cm/sec, we can have $\delta \fallingdotseq 17'$ and result is agreed fairly well with the observed value.

3-3. Observation on the 20th, Dec. Fig. 4 (f) shows the results of observation on the 20th, Dec. This observation line was almost same as of (a). There was no remarkable current (the velocity was below 0.5 kt), unlike on the 16th, Dec. of (a), and the temperature was almost constant and about 19°C except the lower temperature zone very near Shionomisaki. This seems to be caused from the fact that the Kuroshio left farther from

the coast than on the 16th, Dec.

§4. Observation on the 12th, Feb. in 1957.—From the temperature distribution in Fig. 7, we can see the abrupt change near the coast and the gradual change in the offing of about 5 miles. In the velocity distribution, the abrupt increase appears near the coast at the same spot as the temperature, but at offing where the temperature begins to increase, the velocity shows its maximum.

§5. Observation on the 14th, Feb. in 1957.—Fig. 8 shows temperature and current distribution at the boundary of the "cold water mass" and Kuroshio off Enshūnada. Compared this with §4. mentioned above, the temperature, in general, is lower 1~2°C in spite of being at the northern extreme of Kuroshio in the same season, and the change of temperature of three of four steps is more complicated. The change of velocity is more complicated too. These show there exists the complex mixing on the boundary of the cold water mass and the Kuroshio off Enshūnada.

§6. Conclusion—To our great regret, we could not observe the structure of the Shiome below the surface (called the frontal layer) because we could not take advantage of B.T. to our content. An automatic salinity recording analyzer would give us more detailed and fuller informations.

The structure of the Shiome is so complex that we can not draw many certain conclusions from a few data mentioned above, but we can at least conclude from the observation that (1) the abrupt change of velocity takes place at the slight north of the place of the abrupt change of temperature, (2) the both changes of velocity and temperature are in the manner of stair-case and (3) at the southern part of cold water mass off Enshūnada, the Kuroshio intrudes into the cold water.

Acknowledgment—The authers wish to express their thanks to Mr. Inoue, chief of Tanabe Maritime Safety Base and the members there and also Captain "Yoshida" and the crews of the patrol ship "Kumano" who

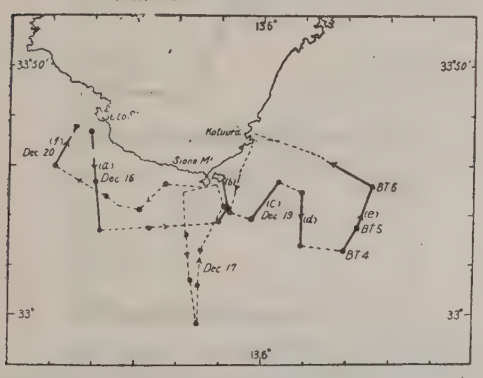

Fig. 1. Cruise pattern.

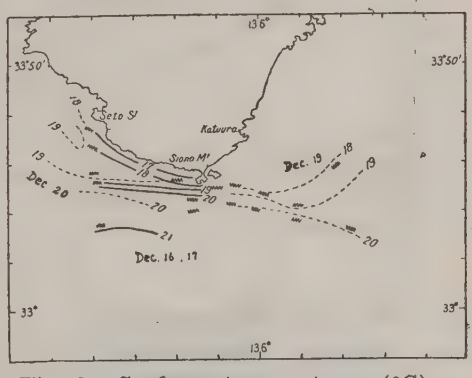

Fig. 2. Surface temperature (°C) (Zigzag line shows the zone of Siome)

assisted in our observations.

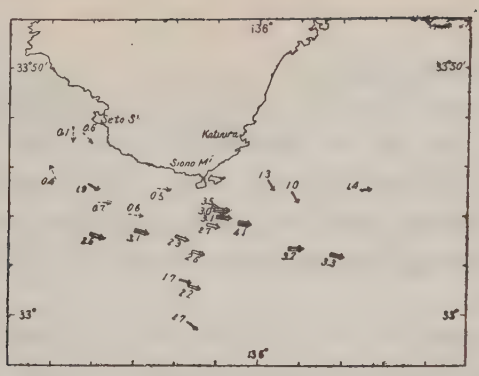

Fig. 3. Surface Current (kt), observed by G.E.K.
(Doted arrow shows current on 20, Dec.)

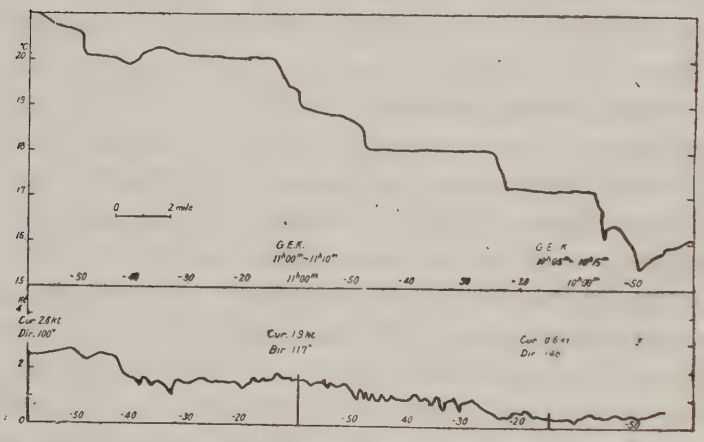

Fig. 4.e. Continuous Record of Surface Temperature and current component on Cruise (e).

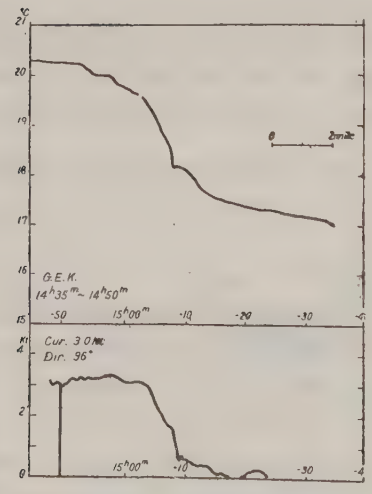

Fig. 4.b. Continuous Record of Surface Temperature and Current Component on Cruise (b)

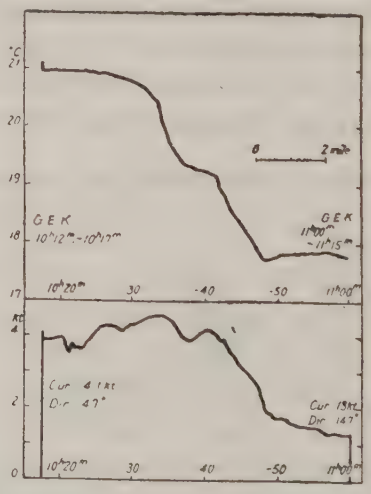

Fig. 4.c. Continuous Record of surface Temperature and Current Component on Cruise (c)

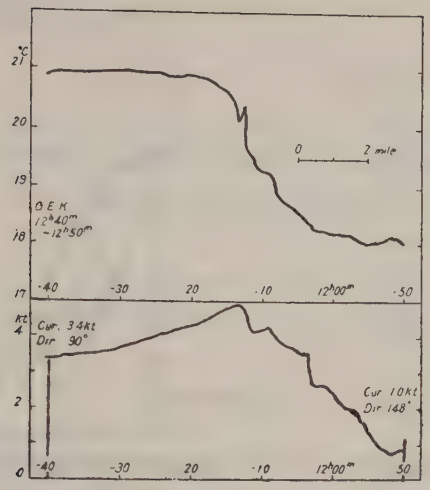

Fig. 4.d. Continuous Record of Surface Temperature and Current Component on Cruise (d)

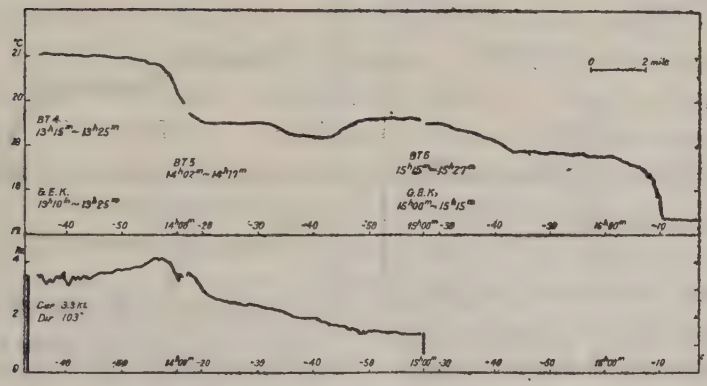

Fig. 4.e. Continuous Records of Surface Temperature and Current Component on Cruise (e).

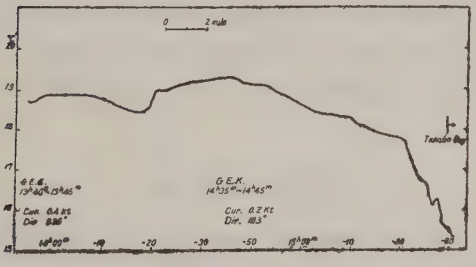

Fig. 4.f. Continuous Record of Surface Temperature on Cruise (f)

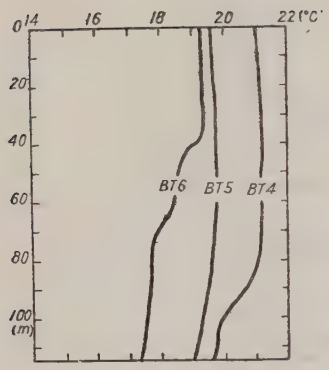

Fig. 5. Virtical Distribution of Temperature at BT.4, 5 and 6.

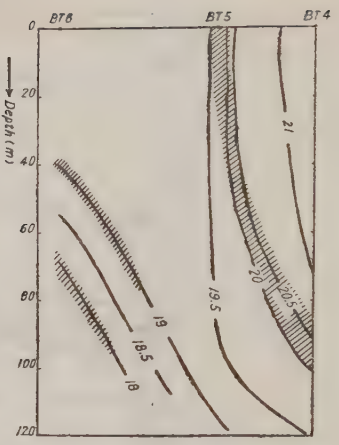

Fig. 6. Vertical Section of Temperature (°C) on Cruise (e) (Shaded Zone shows Frantal Layer)

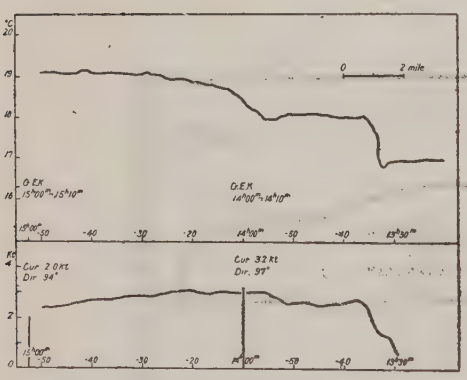

Fig. 7. Continuous Record of Surface Temperature and Current Component off Shiono-Misaki. (on 12, Feb. 1957.)

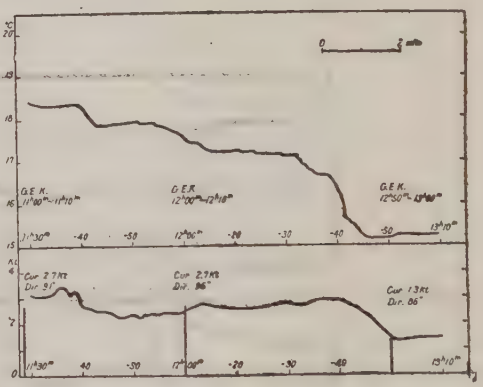

Fig. 8. Continuous Record of Surface Temperature and Current Component off Omaesaki.

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COASTAL UPWELLING, COASTAL CURRENTS, AND THEIR VARIATIONS

By Kozo Yoshida
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Introduction

The upwelling process along continental coasts is of great importance to biological conditions in the coastal waters. In addition to its direct effect through the upward transport of nutrient-rich waters into the euphotic zone, the upwelling must also give indirect effects through the variations in coastal circulation which is associated with changes in density distributions due to vertical advection of mass and also with horizontal divergence of the motion. No satisfactory study on the dynamics, which may relate quantitatively upwelling to the associated coastal currents, has ever been made. Especially, the time transient problems are desirable to be considered, since most of the coastal upwelling is likely to be seasonal or intermittent process, and then upwelling leads essentially to changes in mass distributions. In connection with certain specified areas, layers and periods, what we need should *not* be the average distributions of properties and motions which might be obtained from the usual survey with wide spacing of the observations and without regard to time changes. The interpretation as well as the planning of the observations should require more understanding on nature of variations in oceanic circulation. Thus, some theoretical consideration on time changes in the oceanic motions and their dependenc upon scales of the phenomena concerned might give us a rough idea concerning how quickly and how densely we should cover the specified areas in order to obtain any results of certain significance. Only a summary of theoretical studies is given in this paper which the present author has made in connection with the problems as described above.

Theoretical Model

The whole discussion in this paper is based on a theoretical model in which a two-layer ocean is assumed with each layer homogeneous in density. The changes in pressure field in the ocean are associated partly

with those in the ocean surface slope and partly with those in internal density structure. The density change is represented in this model by a deformation of a thermocline interface separating the two layers of different density. Although the time constants for the responses of the ocean to the changes imposed by external actions such as atmospheric disturbances are not yet known to us at present, they are very likely to depend materially and somewhat systematically upon the scale of the disturbances. The dependence of the rate of the surface slope changes and of the desnity changes upon the scale will differ from each other. Under certain conditions, contribution of density changes to pressure changes is negligibly small, whereas, under some other conditions, the density changes are appreciable. The former type of motions refers to the barotropic motions, and the latter to the baroclinic motions. The free motions which may only represent the possible motions under certain external forces or applied boundary conditions reveal a finite number of modes of the motions for the assumed density model. Some of the modes are of barotropic ones and some others are of baroclinic. If the wind actions are specified and hence if the scale of the motions induced in the ocean is specified, the relative magnitude of each of barotropic and of baroclinic modes is determined. For instances, the motions of ocean-wide scales and of periods as short as a few days are almost purely barotropic, provided that the ocean is unbounded. On the other hand, the motions of wavelengths as short as a few hundred kms would reveal highly baroclinic modes for the periods as long as several years. It is the main purpose of the present work to consider the responses of the oceanic system of forcing actions of different scales. The present author has published a paper in 1956 on this subject (Yoshida, 1956) in which only forced motions are discussed. The paper published by Veronis and Stommel on similar problem contains more extensive treatment of the responses including the discussions of free faves. (Veronis & Stommel, 1956). Both of these works assume the unbounded ocean, that is, the ocean without coastal boundaries. The free motions discussed in the latter paper assume, therefore, a normal mode of the sinusoidal wave form.

In the present paper, on the other hand, the processes near the coastal boundaries are considered. Owing to the presence of the coasts, the free motions must occur in addition to the forced motions. Let us first confine ourselves to the motions induced by the winds which blow parallel to the coast, change their velocity with periods of the order of weeks to months, and are quite uniform over the distance at least several hundred kilometers from the coast. Such winds are supposed to be responsible for large vertical motions along the coast and for large variations in coastal current

system. It is then found that each of two baroclinic free waves has its appreciable amplitudes only confined within about 100 kms from each of the coastal boundaries. This corresponds to the coastal phenomenon which has been discussed as a coastal upwelling some times ago by the present author (Yoshida, 1955, Yoshida & Tsuchiya, 1957). This type of motions is determined almost completely by the wind conditions within distances of a few hundred kilometers from the coast and does not depend upon the conditions further offshore. If the winds have large horizontal shear within such distances, however, the motion will be altered. The presence of shallow shelf region over some distances from the coast, as seen in some parts of edges of the ocean, would reduce the vertical motion at the coast greatly and would shift the zone of large vertical motion to the edge of the deep sea portion. In addition to such baroclinic motions which are pronounced only at the edges of the ocean, two of free barotropic waves would be generated by such wind system. One of these barotropic waves has very large wavelength of the order of the ocean width and has been discussed by Arons and Stommel in connection with the free oscillation of the ocean (Arons and Stommel, 1956). Owing to the large wavelength of this wave, the amplitude of this wave could be considerably large. Detailed discussions of the motions will be made in another paper.

Results

As far as we are concerned with the motions of periods longer than a few days, there are present four types of wave motions in the assumed ocean system.

Denote the zonal and meridional velocities in the upper layer by u and v, respectively, those in the lower layer by u' and v', the vertical velocity by w. Put the suffixes 1 and 2 to the baroclinic and barotropic modes, respectively. The suffixes 11, 12, 21 and 22 refer to each of four modes. w_0 and w_H are the vertical velocity at the sea surface and at the internal boundary, respectively. Each type of motions will be denoted by the symbols, d_1, d_2; or d_{11}, d_{12}, d_{21}, d_{22}. Without regard to the conditions at the opposite side edge of the ocean, the magnitudes of the motions at the coast are obtained for each of d_1 and d_2 modes:

$$\frac{\partial v_1}{\partial t}=\frac{\tau}{H}\frac{H'}{D} \tag{1}$$

$$\frac{\partial v_1'}{\partial t}=-\frac{\tau}{D} \tag{2}$$

$$\frac{\partial v_2}{\partial t}=\frac{\partial v_2'}{\partial t}=\frac{\tau}{D} \tag{3}$$

$$\frac{\partial w_{01}}{\partial x}=-\frac{f\tau}{gH}\frac{H'}{D} \tag{4}$$

$$\frac{\partial w_{02}}{\partial x} = -\frac{f\tau}{gD} \tag{5}$$

$$\frac{\partial w_{11}}{\partial x} = \frac{f\tau}{gH\Delta\rho} \tag{6}$$

and

$$\frac{\partial w_{12}}{\partial x} = -\frac{f\tau}{gD}\frac{H'}{D} \tag{7}$$

where H and H' are the thickness of the upper and lower layer, respectively, D is the total depth of the water τ is the wind stress along the coast, f is Coriolis parameter. g is gravity, and $\Delta\rho$ is the density difference between the two layers. Put the numerical values as follows (all in C.G.S. unit) :

$$\tau=1. \quad f=10^{-4}. \quad g=10^{3}. \quad \Delta\rho=10^{-3}. \quad H=10^{4}. \quad H'=10^{5},$$

Take $\beta=df/dy=2\times10^{-13}$, where y is the meridional coordinate pointing northward and β is the Rossby parameter appearing in the wave numbers of all types of the above modes. Then the order of magnitudes of the velocities are given as illustrated in Table 1.

	d_1	d_2	
		d_{21}	d_{22}
$\lvert w_0 \rvert$	10^{-5}	10^{-5}	10^{-8}
$\lvert w_H \rvert$	10^{-2}	10^{-5}	10^{-3}
$\lvert u \rvert$	1	0.1	
$\lvert v \rvert$	10^{2}	10	
$\lvert u' \rvert$	0.1	0.1	
$\lvert v' \rvert$	10	10	

Table 1. (unit in cm/sec).

It is readily seen from the above Table that the longer barotropic waves, d_{22}, may have very large amplitude of sea level oscillations. The amplitude may amount to the order of 1 to 10 meters for the periods longer than a week. The fact that such enormous oscillations of mean sea level have scarcely been observed may suggest that we must have overestimated this effect or that some other factors might act to prevent this large motions to occur. Yet, this wave may still contain some considerable part of the level changes and is considered to deserve more attention. Note that β effect is essential to the wave. The validity of the above result should be limited to the variations of periods of a week to months. The motions of longer periods may also seem to have this large wave of nearly the same order of amplitude, but there are some things obscure about longer period motions owing to the present lack of knowledge concerning the magnitude of mixing factors. The large horizontal shear or vorticity

in wind stress distributions would prevent the development of this wave. The presence of shallow shelf region adjacent to the coast may also tend to reduce the wave. Remember the conclusion from the author's foregoing work (Yoshida, 1956) stating that: ". . . any perturbation of the wavelength shorter than several hundred kilometers would be baroclinic, whereas the perturbation of the wavelength longer than several hundred kilometers would be so only when T (in sec.) is longer than L/10 to L (in cm)".

Another thing to note is that the meridional current parallel to the coast is strongly accelerated within distances of the order of 100 km from the coast. This coastal current is associated with the baroclinic motions along the ooast which contain pronounced coastal upwelling or sinking. At the same time, the counter current develops in the lower layer, and hence the isotherms or isopycnals reveal a marked "vertical divergence" against the coast. The barotropic currents which are uniform from surface to bottom are also of the appreciable speeds, although they can only be detected by direct measurements of the currents.

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March 1958

ON THE DECAY OF A CYCLONIC VORTEX IN THE SOUTHERN SEA OF HONSHU

(Hydrography of the Kuroshio in relation to its productivity. II)

By Takashi Ichiye
(Japan Meteorological Agency)

1. Introduction

The Kuroshio in the southern sea of Honshū had flown with a conspicuous détour around an intense cyclonic vortex between 136°E and 140°E since the autumn of 1953 (Ichiye, 1955a, 1956b), and such condition seemed to continue further for some years, judging from the previous example of the appearance and maintenance of the cyclonic vortex during about ten years from 1935 to 1943 or 1944 in the similar region. (Ichiye, 1954a, 1955b) However, the present vortex has almost vanished recently, contrary to the expectation derived from the preceding case. In this paper the description about the process of decay of the vortex are given, with some explanations concerning the physical process of such change in the oceanographic conditions.

2. The change of the Kuroshio in temperature patterns of 200 m layer

In order to examine the change in the pattern of the Kuroshio, it is most convenient to take the temperature distribution in the 200m layer, since it corresponds well to the current pattern and yet the temperature in this layer is almost not affected with the annual variation. Therefore, in fig. 1, 2 and 3 the temperatures in this layer are shown by use of all data available, where their

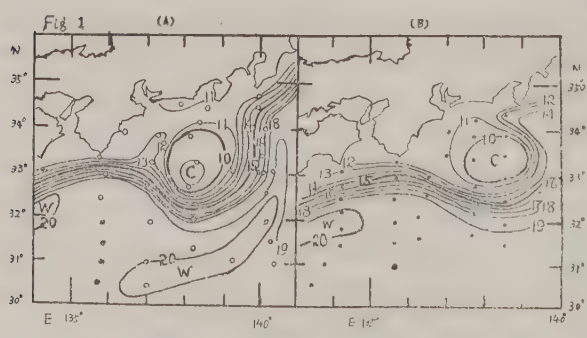

Fig. 1. Water temperature in the 200 m layer.

sources are as follows:

1	(fig. 1 A)	from Oct. 19 to Nov. 1	HO
2	(fig. 1 B)	from Oct. 30 to Nov. 6	KMO
3	(fig. 2 A)	from Feb. 14 to Mar. 5	HO
4	(fig. 2 B)	from Mar. 10 to Mar. 28	KMO
5	(fig. 3 A)	from May 12 to May 27	HO
6	(fig. 3 B)	from June 22 to July 4	TRFI JMA

(HO=Hydrographic Office, KMO=Kobe Marine Observatory TRFI=Tokai Regional Fishery Institute JMA=Japan Meteorological Agency)

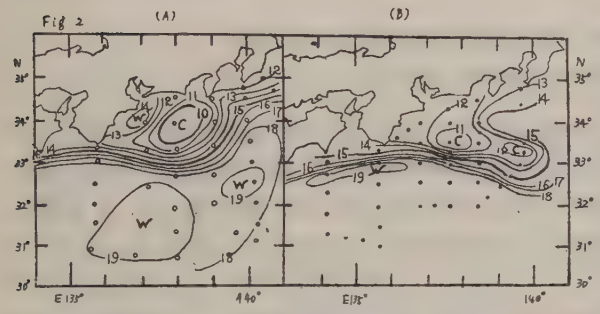

Fig. 2. Water temperature in the 200 m layer.

These figures indicate that the area of the cold water region between 136° E and 140°E was decreasing gradualy since last October. The change of the area seems to be most conspicuous between the observation (2) and (3), partly due to the large interval of about four months. The detailed description of each observation is as follows:

Obs. 1. The area of the cold water region seems to be rather larger than in the observation of August (Oceanographical Section, 1955)

Obs. 2. The area was decreased somewhat from the previous period and the center seems to move northwards by about 20 miles.

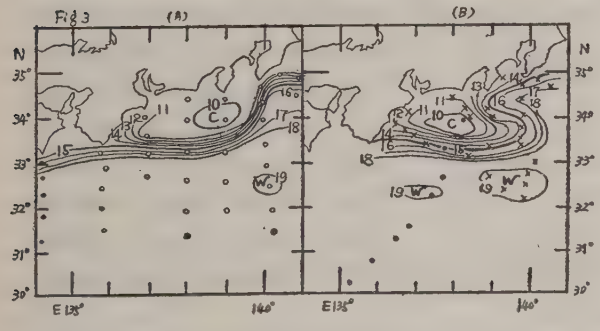

Fig. 3. Water temperature in the 200 m layer.

Obt. 3. The area of the cold water region was shrinked remarkably from the previous observation, the center of which moved northwards by about 40 miles. The form of the cold region became oblong from east to west. The warm water to the east of the Kii Peninsula was advected by the branch of the Kuroshio with the speed of about 0.5 to 0.8 kts of northwest

direction, according to the GEK data of HO.

Obs. 4. The cold region became more oblong than in the previous period. Further, it seems to break down into two parts, with the minimum temperature increasing somewhat from that period.

Obs. 5. The cold region became so shrinked that the Kuroshio flowed eastwards without meandering.

Obs. 6. The location of the boundary of the cold region is somewhat doubtful, because of the scarce distributions of the observation stations, but we can ascertain safely that the Kuroshio to the east of the cold region flowed to NW, instead of N, then turning to ENE. Thus the center of the cold region was displaced westwards by about 60 miles from the previous observation.

3. Comparison with the previous example of the cyclonic vortex

The disappearance of the cyclonic vortex in the previous period of 1935 to 1943 was not observed so satisfactorily as in the present case, and here we indicate the two observations carried out by HO in fig. 4 (HO, 1951), where the surface dynamic topography referred to 800 db level is shown for the periods of April and December of 1943. The topography of the former period indicates the conspicuous meandering of the Kuroshio around an extensive cyclonic vortex, which was larger in its area and was located far south than in the condition of the Obs. 1, and yet it was decreased conspicuously in December, though the area was almost similar to that of the Obs. 2 even in this decay stage. Therefore, the course of the Kuroshio was located in the December case almost at the same latitudes with the Obs. 2.

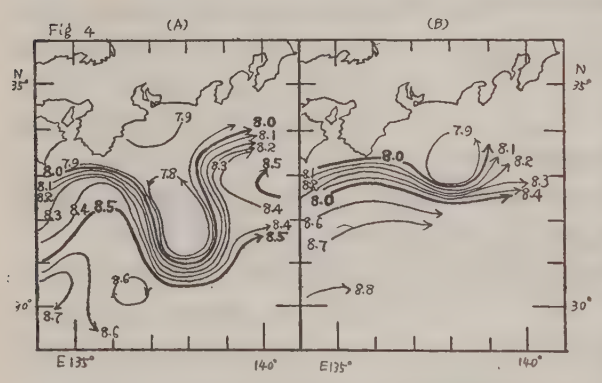

Fig. 4. Surface dynamic topography referred to 200 db layer.
(A): April in 1943 (B): December in 1943.
(The figures in charts should be added with 770.)

The observation in the previous case was not carried out till August of 1946 after then, so we cannot determine the precise time of the disappearance of the cyclonic vortex. Only it occurred between December of 1943 and August of 1946, because the vortex vanished completely in the

last period.

4. Change in the surface water temperatures

The average surface water temperatures of the ten days obtained from the reports of merchant ships as well as those of fishing boats and research ships are shown in fig. 5 and 6 since October of 1956, which indicate the remarkable fluctuations in the pattern in the period between the last ten days of November to the second ten days of January. Such fact seems to correspond to the abrupt change in the area of the cold water region in the 200 m layer as stated in §2. After this period, the course of the Kuroshio which is indicated with the strong gradient of the temperatures was almost close to the coast and ran from west to east, suggesting the decay

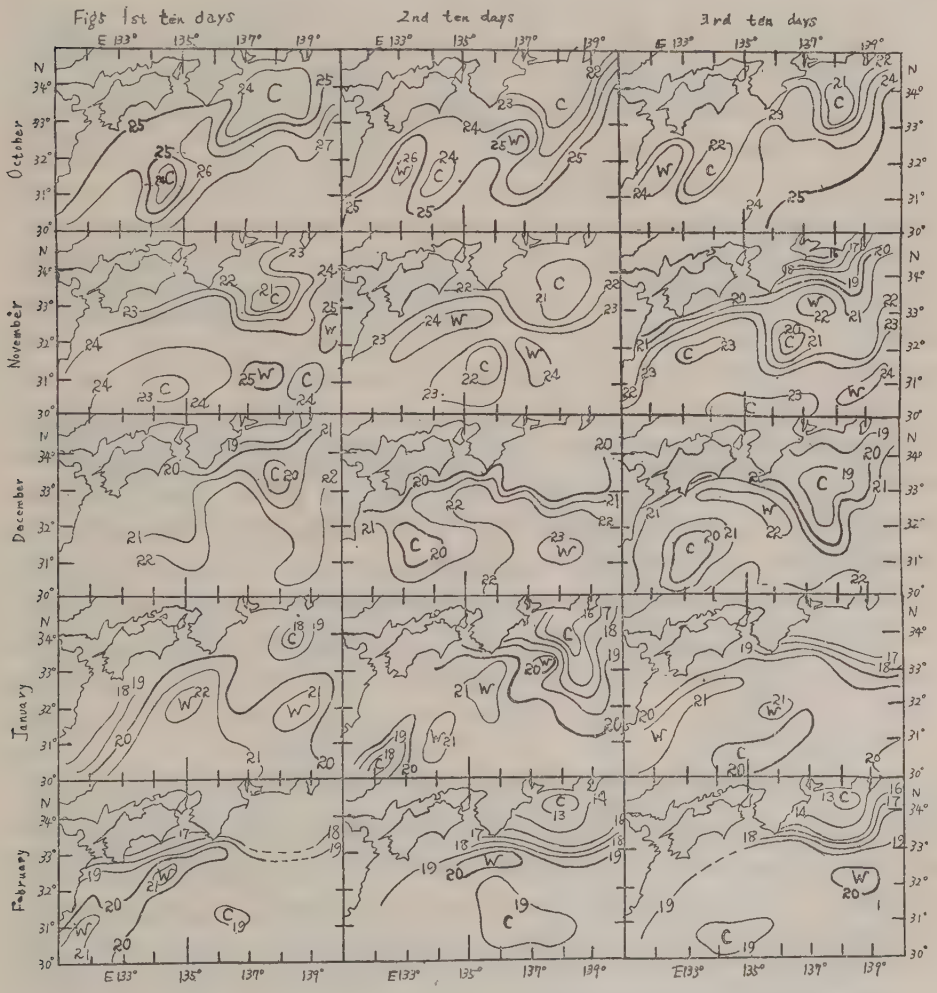

Fig. 5. Ten days mean surface water temperature from October 1955 to February of 1956.

of the cold water region. The most complicated pattern in the considered period occurred in the last ten days of November, where the cold region was observed at about 32°N, 147°E and the maximum gradient zone was splitted in two around this region, suggesting the branching of the Kuroshio. Such splitting was seen to continue to the next ten days, and after then it seemed to disappear, though the details are obscure due to the scarcity of the data. If we consider such splitting to correspond to the branching of the Kuroshio, it is quite analogous to the blocking in the atmospheric jet stream, since in both current systems the splitting of the basic zonal current is a special case, producing a different current pattern from the preceding condition. (Riehl, 1952) Only in the latter system, the general pattern is changed from the predominant zonal one to the meri-

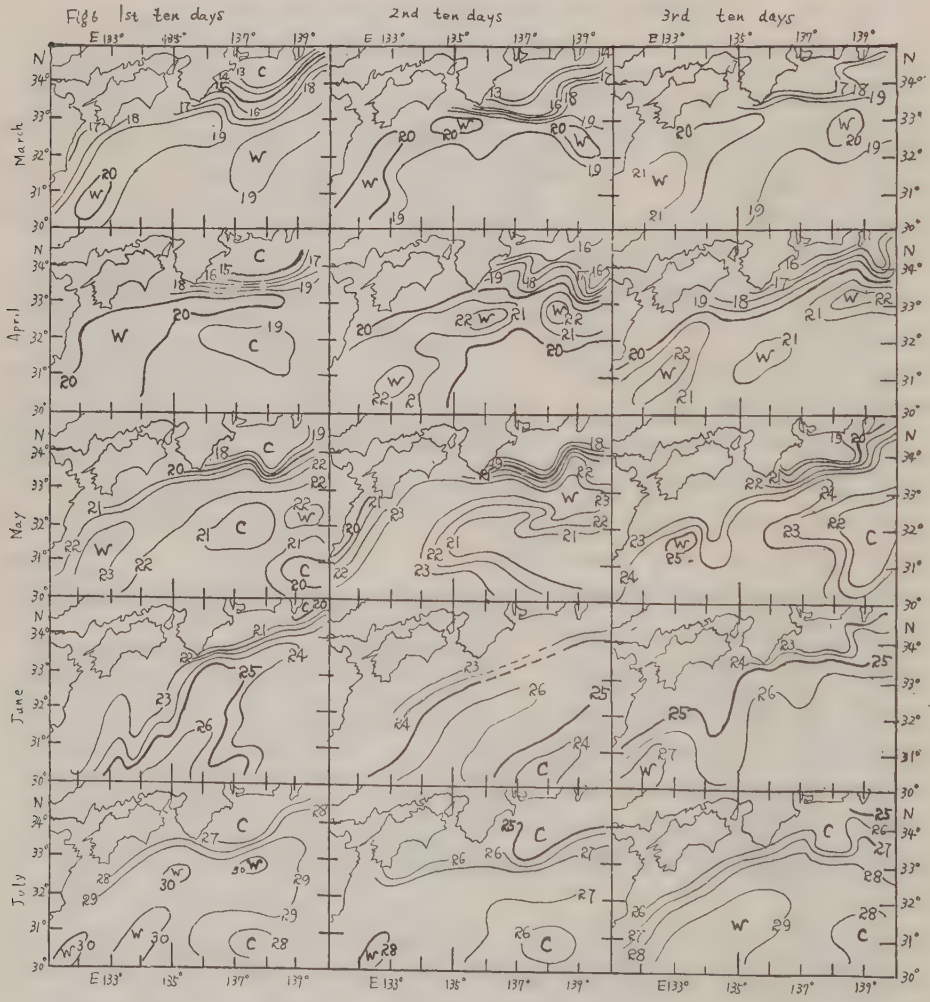

Fig. 6. Ten days mean surface water temperature from March to July of 1956

dional one after the occurrence of the blocking, whereas in the former current system or the Kuroshio the transition is reverse, that is, the conspicuous meridional structure of the current with a cyclonic vortex vanishes, then being transformed into an almost zonal current. (Namias and Clapp, 1952)

In fig. 7 we plot the change of the most southern localities of the maximum gradient zone of temperatures in the surface and 200 m between 135°E and 140°E determined from the temperature charts of fig. 1, 2, 3, 5 and 6. Since the location of the Kuroshio is approximately indicated by the maximum temperature gradient, this figure shows the variation of the meandering of the Kuroshio in the considered region or the change of the extent of the cold water region, though the surface temperature in summer is somewhat inadequate to indicate the current pattern due to its horizontal uniformity. However, it suggests more clearly the abnormal condition from November to December as stated above, which gives the similar change to the blocking stage of the atmospheric jet indicated with the mean cross section of the geostrophic wind (Cressman, 1950). On the other hand, the location of the maximum gradient in 200 m layer is plotted with long intervals, and its change seems to be gradual from October-November to February-March, not suggesting so abrupt change between these periods. Therefore, it is necessary to examine almost continuously the change in the current pattern in such critical cases, though in the present example it was realized only insatisfactorily.

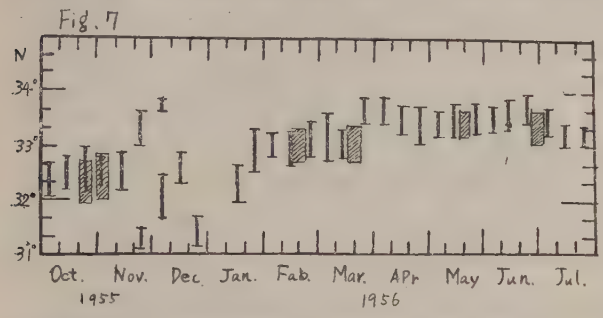

Fig. 7. The change of the most southern location of the maximum gradient zone of temperatures.
(for surface temperature: for 200 m layer temperature)

5. The mechanism of the decay of the vortex

The present example of the decay of the cyclonic vortex might be due to the decreasement of the meandering of the Kuroshio rather than to the dissipation of the vortex itself such as by a diffusion, since it is unreasonable to consider that the effect of diffusion increased so abnormally during the period concerned.

Further, the change of the Kuroshio in the present example seems to be independent with the meteorological effects, contrary to the case of

the abrupt removal of the axis of the Kuroshio from the coast which occurred in July of 1953 (Ichiye, 1954b), since we cannot detect so abnormal phenomena in the merteorological conditions between November of 1955 and February of 1956. (Geophys. Review, 1955, 1956).

Therefore, we should consider the cause of such change to be due to the structure of the Kuroshio, and in order to see the difference in the dynamical properties of the Kuroshio in the period of the strong and weak meandering we plot in fig. 8 the zonal velocities at four sections between 135°E and 140°E obtained with GEK are plotted against the distance across the current where the zonal velocity means the component parallel to the course of the Kuroshio determined by the temperature pattern of 200 m layer. The GEK data are obtained only in the observation (1), (3) and (5), and the mean maximum velocity U_m, the breadth of the main current of the Kuroshio B, which is defined as the zone with the velocity larger than 1 knot and the mean shearing vorticity $-\partial u/\partial y$ in the right and the left half of the Kuroshio determined by least squares from the data plotted in fig. 8 are shown in the next table

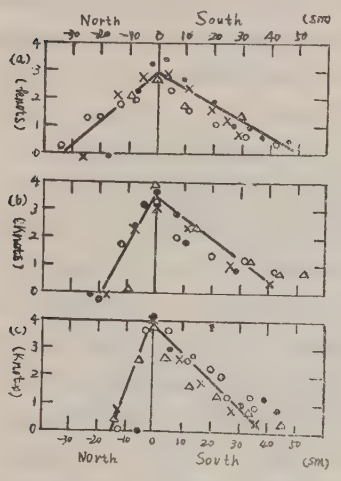

Fig. 8. The zonal velocities measured with GEK at four sections across the Kuroshio between 135°E and 140°E. (a) Obs. 1 (b) Obs. 3 (c) Obs. 5
(● about equal to 136°E × to 137°E ○ to 137°-138°E △ to 139°-140°E)

Obs.	U_m(kts)	B(sm)	$-\partial n/\partial y$ ($\times 10^{-5}$ sec^{-1})	
			left	right
(1)	2.6	57	1.83	−1.29
(3)	3.4	48	4.64	−1.91
(5)	3.9	42	6.87	−2.44

Figure 8 and this table suggest that the meandering decreases with the increasing velocity of the Kuroshio and its decreasing breadth, which is contrary to the case where the assumption of the constant absolute vorticity is valid, since the velocity with trajectory has larger amplitude for the increasing velocity with the equal incident angle ϕ_0 (Rossby, 1940; Ichiye, 1956a), though in the present examples the incident angle ϕ_0 in each observation is not so accurately determined due to the scarcity of the GEK data in the western section to 135°E. On the other hand, the correspondence between the current pattern of the Kuroshio and its velocity seems to be analogous to the relation between the general circulation pattern and the zonal index, as indicated by Willet (1949), where the strong velocity

with the narrow breadth of the Kuroshio corresponds to the high index, resulting in the predominant zonal motion and the weak current of the Kuroshio to the low index, accompanying with a meandering of the current or the jet stream and having a cellular structure. (Namias, 1950)

In any case, the splitting of the current in November and December seems to be the direct motive for the decreasement of the mandering, and it forms the necessary stage of the cycle of appear and disappear of the cyclonic vortex, corresponding also to the blocking pattern of the atmospheric jet in the zonal index cycle (Petterssen, 1956). This is further confirmed from the fact that similar splitting of the Kuroshio was observed in July of 1953, which caused the appearance of the cold region considered here (Ichiye, 1954b), contrary to the present case. Therefore, if the cause of such splitting is known, the decay of the meandering may be explained.

Rossby (Berggren, Bolin and Rossby, 1949) discussed the blocking phenomenon in the atmospheric jet with analogy to a hydraulic jump. Here the author gives a theoretical treatment of the problem being adequate to the ocean current, following him.

First, we assume that the Bernoulli's relation is valid along the streamline of the Kuroshio, and we have

$$qdq+dp+dF=0 \qquad (1)$$

along the narrow current within the surrounding resting current, where q is velocity, p, pressure and F is frictional force. When we take the velocity profile such asg iven in fig. 8, the mathematical expression for the zonal velocity u becomes

$$u=U_m r/a\,(a>r>0)=U_m(b-r)/(b-a)\,(b>r>a)$$

where r means the horizontal distance across the current, and b is the breath. Then we may replace q with u the mean velocity in each section, which is given by

$$U=U_m/2=Q/b$$

where

$$Q=\int_0^b u\,dr=U_m b/2$$

is total current flux and constant along the current. On the other hand, when we assume that the geostrophic relation is valid for r-direction, we have

$$\partial p/\partial r=-fu \qquad (2)$$

Further, when the current is considered to be almost parallel to latitude circles, we can put

$$f=f_0+\beta r$$

where h the depth of the water, g the gravity constant and f_0 is the incli- of the current, being variable along the current. Putting f and u in (2) and integrating it with r, we have ,

$$p-p_0=f_0Q+\beta Q(a+b)/3 \qquad (3)$$

where p_0 is the pressure at the northern boundary, and it is constant, since the Kuroshio approaches to the coast there.

When we take s as the distance along the current, the equaltion (1) becomes

$$-\frac{U^2}{b}\frac{db}{ds}+\frac{\beta}{3}Q\frac{d(a+b)}{ds}+Q\frac{df_0}{ds}+\frac{dF}{ds}=0, \qquad (4)$$

or putting $a=\sigma b$ we have

$$-\frac{U^2}{b}\frac{db}{ds}+\frac{\beta}{3}Ub(1+\sigma)\frac{db}{ds}+Q\frac{df_0}{ds}+\frac{dF}{ds}. \qquad (4')$$

This equation is similar to that of the flow in a open channel, which is given by

$$-\frac{U^2}{h}\frac{dh}{ds}+g\frac{dh}{ds}-g\alpha+\frac{dF}{ds}=0 \qquad (5)$$

where h the deapth of the water, g the gravity constant and is the inclination of the bed.

As generally known in hydraulics, $U_c=\sqrt{gh}$ is the critical velocity and a hydraulic jump occurs at the region where the flow with velocity $U<U$ (jet flow) changes to that with $U>U_c$ (ordinary flow). (Rouse, 1950) By comparing (5) with (4'), we might take the critical velocity of the ocean current as $U_c=\beta b^2(1+\sigma)/3$, which is different in factor $(1+\sigma)$ to that obtained by Rossby, since the velocity profile here assumed is different from that given by him. However, it is reasonable to consider that the splitting of the current may occur for the case of the change from $U>U_c$ to $U<U_c$ with analogy to the hydraulic jump, as shown in the blocking of the atmospheric jet by Rossby.

On the other hand, the current flux Q within the upper layer of one meter depth is computed from the velocity profile in fig., which is given by

Obs. (1) 1.02 Obs. (3) 1.01 Obs. (5) 1.00 ($\times 10^5 m^3$)

and these values are considered to be equal within errors of observation. Therefore the total flux seems to be almost constant with time, and on the contrary, the values of critical ratio $n=3U/b^2\beta(1+\sigma)$ computed from the same velocity profile are as follows:

Obs. (1) 2.78 Obs. (3) 5.9$ Obs. (5) 9.24

These values may be overestimated, due to the underestimation of the breadth b from the assumption of linear velocity profile. So we can consider reasonably that in the period of the splitting, that is, in November or December, this critical ratio n became less than unity within the considered region between 135°E and 140°E due to the much increasing meandering, whereas it was higher than unity to the west of it similar to the values of Obs. (3) and (5) thus the splitting occurred, corresponding to the hydraulic jump. After then, the southern branch of the current seems to be confluent to the northern one, resulting in the northward movement of the Kuroshio in the considered region. In the current condition of Obs. (3) and (5), the critical ratio n is far larger than unity, and also the large horizontal stability $f-\partial u/\partial y$ on the northern boundary of the current as shown above may contribute to maintain the Kuroshio without further splitting or meandering.

7. Conclusion

The cyclonic vortex which was maintained from 1953 has decreased its extent since March of 1956, and the change in the condition of the Kuroshio is traced here by use of the data all available. Such decay seems to accompany with the splitting of the Kuroshio, similar to the blocking of the atmospheric jet. The mechanism of splitting is explained also with analogy to the hydraulic jump.

Acknowledgement. The author expresses his hearty thanks to Dr. Koji Hidaka for kind encouragements and also to the UNESCO Committee for Oceanic Productivity for financial aids.

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TURBIDITY DISTRIBUTION AND ITS RELATION TO SOME OCEANOGRAPHICAL FACTORS IN THE EASTERN CHINA SEA IN THE LATE SUMMER OF 1956

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(Faculty of Fisheries, Hokkaido University, Hakodate)

Resumé

The turbidity distribution in the Eastern China Sea in the late summer of 1956 was observed by a turbidity meter of simple structure. Several water masses were distinctly analysed by the extinction coefficient observed. Sharp knees of turbidity occurred at the spring layer of density were noticed and explained by the sudden decrease of vertical eddy diffusivity. The existence of distinct minimum of turbidity at the maximum density gradient was especially demonstrated and the development of intensive mixing in horizontal direction at the spring layer was suggested. In the oceanic homogeneous water to the right of the Kuroshio axis, the downward transport of suspended detritus was calculated from the observed vertical distribution of turbidity and phyto-plankton production at each level was also discussed.

Introduction

In recent years, measurements of suspended loads in the sea have increased in importance in several fields of oceanographic researches: in the studies of water mass analysis, stratification of waters, mixing processes of different waters, phyto-plankton productivity, etc.

In 1953 a turbidity meter was designed (M. Fukuda, N. Inoue and S. Nishizawa, 1954), using a photo-tube and a sinusoidally modulated light beam, which made it possible to measure turbidity of sea water *in situ* without its being disturbed by any daylight action. Preliminary measurements were made in the Ishikari Bay and some coincidence were found between the turbidity distribution and the hydrographic factors in the Bay. M. Fukuda and N. Inoue (1958) have improved the turbidity meter designed in 1953 in some points and especially succeeded in obtaining higher stability of amplification of electric current generated in the photo-cell by means of a push-pull type circuit. Measurements were made in the northern North Pacific and Bering Sea in the early summers of 1955 and 1956 (N. Inoue and M. Fukuda, 1958). It was ascertained then that sharp subsurface peaks of turbidity occurred at the boundaries of light shallow layers just above the dense water.

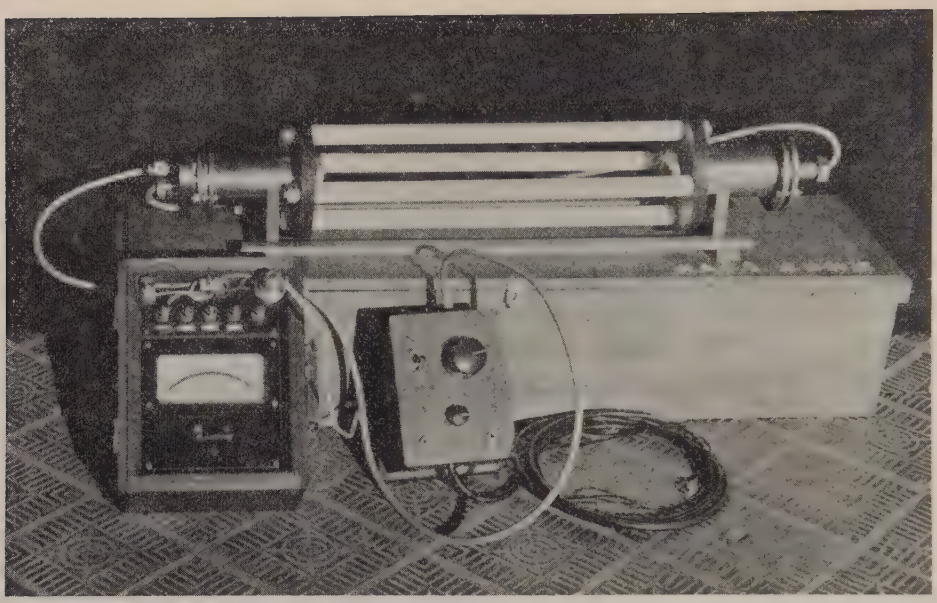


Fig. 1. The exterior view of the turbidity meter used in the present observation.

The instrument described here was constructed with the aim of attaining a system of simple structure and consequently easy operation on board ship. In 1956, turbidity measurements were made with this instrument in the Eastern China Sea during the observation cruise of the Sōyō Maru in September and October. Some results are reported here.

Instrument

The exterior view of the instrument used in the present observation is shown in Fig. 1. It is constituted of two parts, the light source chamber and the light receiving chamber, connected to each other rigidly by four parallel iron pipes 55 cm long. The light source is a 6v-8w tungsten lamp, the filament of which covers an area of 1.5×1.0 mm and is lighted from batteries on board. The light, passing a collimating lens, runs a 50 cm pass and enters the light receiving chamber, in which it is converged by a condenser lens on the surface of a photo-cell (Fig. 2).

The light beam of 30 mm diameter which runs through between the chamber is not strictly parallel but is so adjusted that it focusses into an image of the filament on the window glass of the light receiving chamber for the sake of easily reproducible standardization of the optical system. The effective receiving area of the photo-cell is restricted to a 3 mm diameter, so that the sunlight disturbance is negligibly small. In the light source chamber, another photo-cell of the same size as in the receiving chamber is set on the side of the lamp opposite to the collimating lens, which serves as a compensation element for the fluctuation of the luminance

intensity of the lamp. In each chamber is placed a ring-shaped cage of wire gauze filled with desiccant agent. Furthermore, an electric heater of 3 watt is inserted in the receiving chamber to keep the temperature of

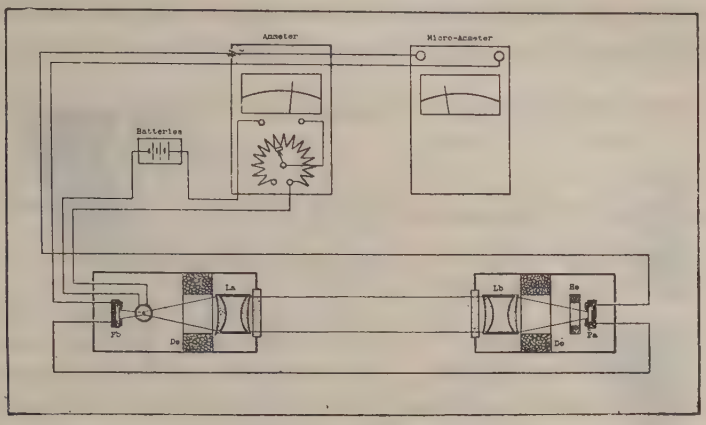


Fig. 2. The optical system of the turbidity meter and the measuring circuit. L: Tungsten lamp, Pa: working photo-cell, Pb: compensating photo-cell, Lcol: collimating lens, Lcon: condenser lens, De: desiccant agent, He: electric heater.

~~which serves as a compensation element for the fluctuation of the luminous~~ the chamber almost the same as that of the light source chamber. This is effectual on the one hand to maintain a low relative humidity in both chambers and on the other hand to keep the temperature of each photo-cell nearly equal, for without the insertion of the heater the sensitivity of the two photo-cells would differ to some certain extent owing to temperature difference. The present instrument was tested in the laboratory to show negligibly small influence of temperatures between 0° and 30°C of water in which the system was immersed.

The standardization of the whole system is so made that no current flows when the instrument is placed in the air. In the laboratory the micro-ammeter reading is calibrated to extinction coefficient previously to the observation cruise.

The cab-tyre cord is 200 m long and 4 threaded, two of the threads being steel wire lines. The instrument was dipped vertically and hung directly from the cab-tyre cord at desired depths.

The vertical distribution of turbidity is commonly very complicated and often makes sudden changes in a few meters of depth, so that the accurate determination of depth at which the turbidity measurement is being made is especially desirable. In the present observation, the authors attached a specially designed electric depth meter to the turbidity meter and observed simultaneously the depth and the turbidity.

Results of observation

Oceanic Water: The location of stations is illustrated in Fig. 3. The arrows in the figure represent the main features of current system of the region. The axis of the Kuroshio Current passes through station 7 northeastwards following the contour lines of about 500 m to 600 m depths and

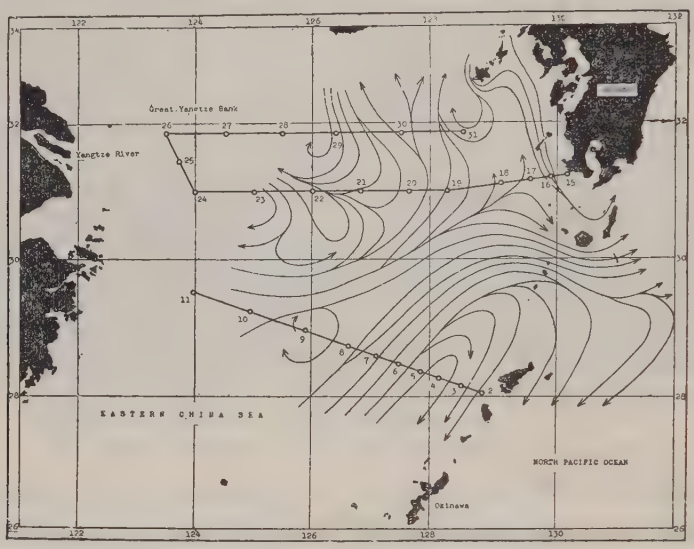


Fig. 3. Positions of stations occupied in the observation cruise of Sōyō Maru in September 20 to October 3, 1956. The current system of the Eastern China Sea is also illustrated which is based on the current measurement by G.E.K. performed by the Nagasaki Marine Observatory in June 25 to July 16, 1956.

bends east pouring into the Pacific through the Tokara Strait, sending northwards a branch, called the Tsushima Current, which passes through stations 19 and 30 and continues to flow through the Tsushima Strait into the Japan Sea. Between the axis of the Kuroshio and the Okinawa Islands there develops a large clock-wise eddy in which waters are very transparent, the visual ranges of Secchi disk being all beyond 20 m; at station 4 it was 30 m or more. The vertical distributions of turbidity (extinction coefficient per meter) in these waters are illustrated in Fig. 4, in which the vertical distributions of density (σ_t) are also inserted for the sake of comparison. In these regions no remarkable thermocline is found in this season, the density increasing slightly and uniformly downwards. The turbidity is also very uniformly distributed, ranging mostly between 0.14 and 0.16 in extinction coefficient per meter. The turbidity, however, increases slightly with depth in the shallow layer and decrease slightly with depth in the deep layer, forming thus a weak maximum of turbidity

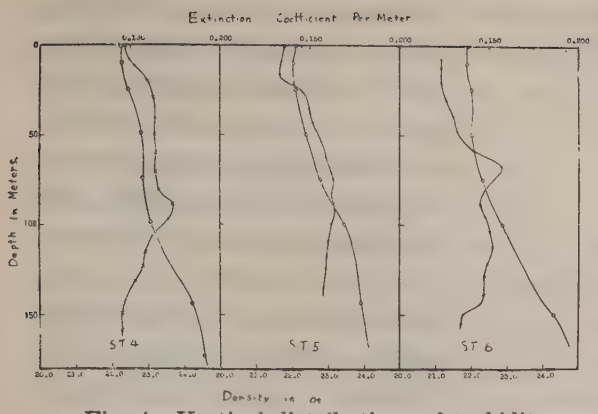


Fig. 4. Vertical distributions of turbidity (lines through crosses) and density in (lines through circles) in the oceanic homogeneous water in the large clock-wise eddy developed to the right of the Kuroshio axis.

between 75 m and 120 m depth. Within this relatively turbid zone, the values undulate to a small extent and several poor peaks of turbidity are often found as indicated in Fig. 4. It is noticeable that within this turbid zone the density gradient is also greater than outside. The surface layer above 50 m is generally transparent in comparison with deeper layers in these oceanic homogeneous waters.

~~also greater than outside. The surface layer above 50 m is generally transparent in comparison with deeper layers in these oceanic homogenous waters.~~

Waters on the Continental Shelf:—The vast area covered by the continental shelf of this region is occupied by several different water masses and a complex field of current system (see Fig. 3). A branch of the Kuroshio extends from the south over the shallow region as far north as 31°N, while the vast volume of run off water of the Yangtze River from the west and the cold water of the Yellow Sea from the north are pouring into this region. Along the boundaries of these water masses, there are formed sharp current ripples or large-scale horizontal eddies. Sharp spring layers between the light shallow waters and the cold bottom waters attain stable development in almost all parts of the shelf especially in the northern area all the year round. Typical vertical distributions of turbidity are shown in Figs. 5, 6 and 7 as well as density distributions at the same stations.

In the first section (through stations 2 to 11) the spring layer of density at station 8 is located at the depth of 80 m and the density gradient in upper layer is rather great, showing some intensity of mixing through the spring layer. The turbidity gradient is almost parallel to the density gradient in upper layer; in the bottom layer, where the water has very homogenous distribution of density of 24.7 in σ_t value, the turbidity of water shows a peculiar vertical distribution having a remarkable maximum of 0.30 in extinction coefficient at the depth of 100 m. The same phenomenon is also observed at station 20 (see Fig. 6) which is located, just like station 8, at the edge of the continental shelf being contiguous to the

axis of the strong current. It is of interest to note that the maximum gradient or "the knee" of turbidity occurs some ten meters deeper than the maximum density gradient. At the next station (station 9) the density stratification is highly stable and the layers above and below the spring sheet are very homogeneous in density in each different value. The turbidity, however, increases very rapidly with increasing depth especially in the bottom layer where the extinction coefficient at 104 m depth is 0:59; in deeper layers the values exceed 0.6. The sharp turbidity gradient or the knee occurs at the depth of 80 m, while the spring layer of density is located at a shallower depth of 70 m, just as at the former station. The surface layer at this station down to 30 m depth is less turbid, below 0.20 in extinction coefficient, than at neighbouring stations; this suggests a surface extrusion of a branch of the Yellow Sea water reaching as far as this section, which, however, is not so clearly identified in temperature and salinity distributions as in turbidity distribution. At station 10 (Fig, 6), the whole column of water is very turbid exceeding 0.25 in extinction coefficient. In shallow layer it decreases slightly with depth but in deeper layer it increases very rapidly, thus developing a remarkable turbidity minimum layer at the depth of 50 m at which the maximum density gradient occurs. The knee of turbidity, therefore, is located about ten meters deeper than the density spring layer at this station also.

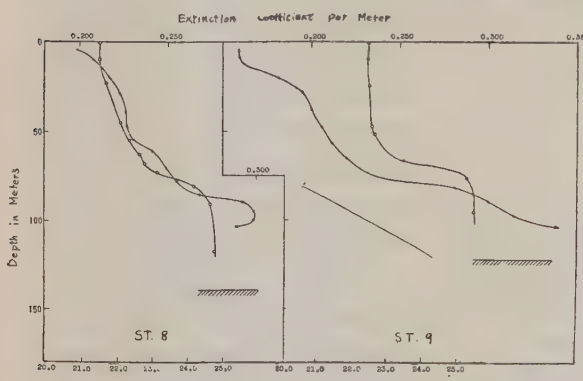


Fig. 5. Vertical distributions of turbidity (lines through crosses) and density in (lines through circles) in the continental shelf waters at the first section (through stations 2 to 11).

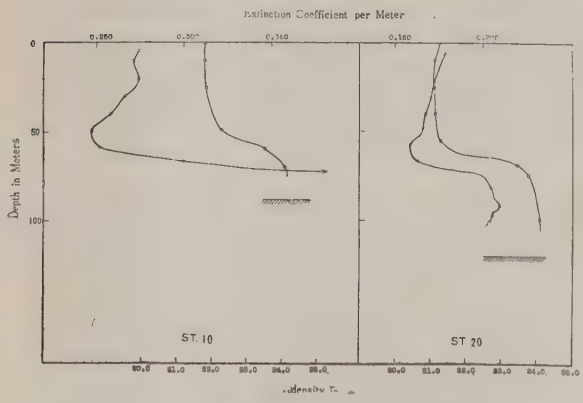


Fig. 6. Vertical distributions of turbidity (lines through crosses) and density in (lines through circles) in the innermost region of the continental shelf (station 10) and at the periphery of the shelf (station 20).

In the second section (through stations 15 to 24),

general aspects of turbidity distribution are similar to those of the preceding section but the turbidity stratification is more distinct as shown in Fig. 7 At station 21, a very interesting curve of of vertical distribution of turbidity is observed. In this area, a triplicate stratification develops, the vertical density distribution being composed of three distinctly different layers each of which is very homogeneous in density. The corresponding turbidity distribution is also triplicate: the surface layer down to 30 m is homogeneously turbid at 0.20 in extinction coefficient, the intermediate layer down to 70 m is likewise homogeneously turbid at 0.35 and the especially turbid bottom layer increases very rapidly turbidity towards the bottom. At the shallow spring layer, a conspicuous turbidity minimum is formed at the depth of maximum density gradient, and at the lower spring layer the same minimum is developed, its depth, however, being a little shallower than the corresponding maximum density gradient. At station 21, the shallow layer is again occupied by the light and transparent (below 0.20 in extinction coefficient) water of Yellow Sea origin and just above the turbid bottom layer a noticeable turbidity minimum is observed corresponding to the sharp density gradient. The same minima are also observed at the northern stations 28 and 28 (not shown in Fig. 7 but see Fig. 10).

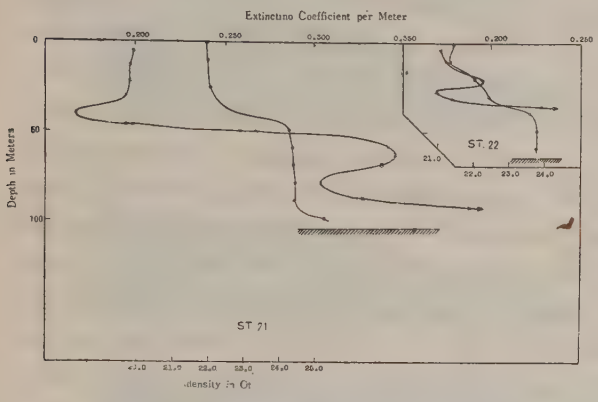


Fig. 7. Vertical distributions of turbidity (lines through crosses) and density in (lines through circles) in the continental shel waters at the second section (through stations 14 to 24).

Coastal Waters: The area to the southwest of Kyushu Island is occupied by the weak compensating or counter current for the northward flow of the Tsushima Current; the turbid waters on the continental shelf contribute little to the waters of this region. Therefore, the water are fairly transparent and the turbidity values are generally below 0.17 in extinction coefficient. The typical turbidity distribution is illustrated in Fig. 8. The values show no remarkable undulation with depth notwithstanding the fairly sharp density gradient occuring in the middepths. The shallow layers are comparatively turbid showing high productivity of phyto-plankton in coastal regions. At station 31(see Fig. 10), which is located at the center of a clock-wise eddy developed to the south of the

Danjo Islands, the water is expressly clear, just as it is at stations 4 to 6, except at the sea surface. The high turbidity which is often found at the sea surface especially in the coastal region (stations 16 and 31) is probably ascribable to some dense population of micro-organisms or waste material from ship or land.

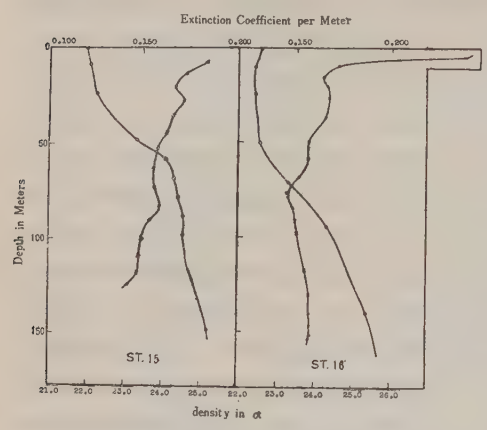


Fig. 8. Vertical distributions of turbidity (lines through crosses) and density in (lines through circles) in the coastal area to the southwest of Kyūshū Island.

Waters in Transition Area: Along the edge of a strong current, there occurs generally an intensive horizontal mixing caused by the high value of horizontal velocity gradient especially where the vertical stability is great. The interesting example shown in Fig. 7 (station 21) is observed at the left side of the Tsushima Current. At station 7 (Fig. 9) which is also located at the border of the Kuroshio Current, the shallow waters above 80 m are mixed with the continental shelf water resulting in rather high turbidity compared with the values in shallow layers at stations 4 to 5, while the deep waters are still purely oceanic. In this area, the horizontal mixing at depths is considered to be greatly restricted by the weak stability resulting in no drastic stratification of turbidity as at station 21. A conspicuously complicated stratification of turbidity is encountered at station 30 which is located at the edge or the axis of the Tsushima Current (Fig. 9, also see Fig. 10). The selection of observed depth at this station is too coarse especially in temperature measurement to determine the fine structure of the stratification in the area; probably some complicated features are likely to be missed out. An isolatball and therefore it must be considered that some temporary convec-ed small "ball" of cold (15.58°C) water of low chlorinity (18.21‰) is found at the depth of 58 m at this station; it is very clear (0.14 in extinction coefficient). The stability is small in the neighbourhood of this

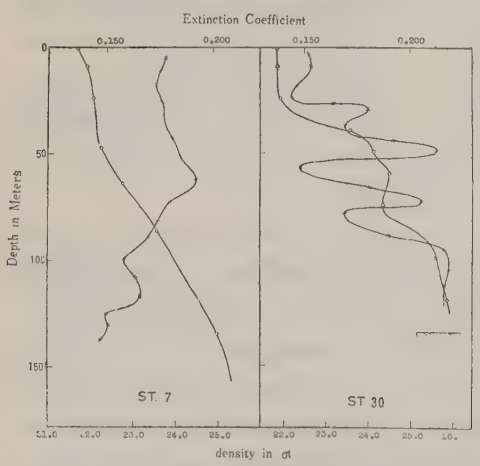


Fig. 9. Vertical distributions of turbidity (lines through crosses) and density in (lines through circles) near the axis of the Kuroshio Current (station 7) and the Tsushima Current (station 30).

tion process was taking place at this station.

The distributions of turbidity together with those of temperature and chlorinity at the first, second and third (through stations 26 to 31) sections are illustrated in Fig. 10.

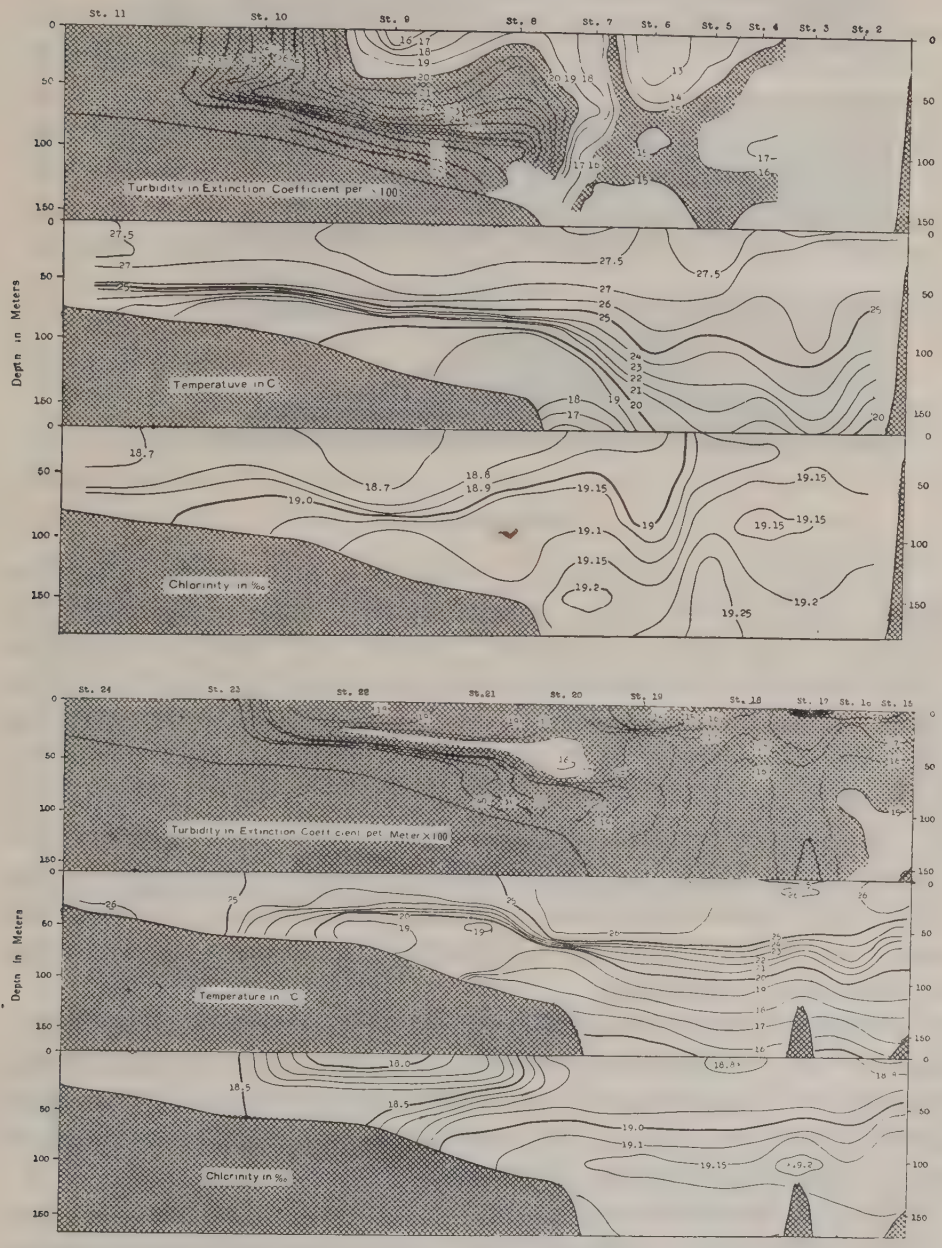
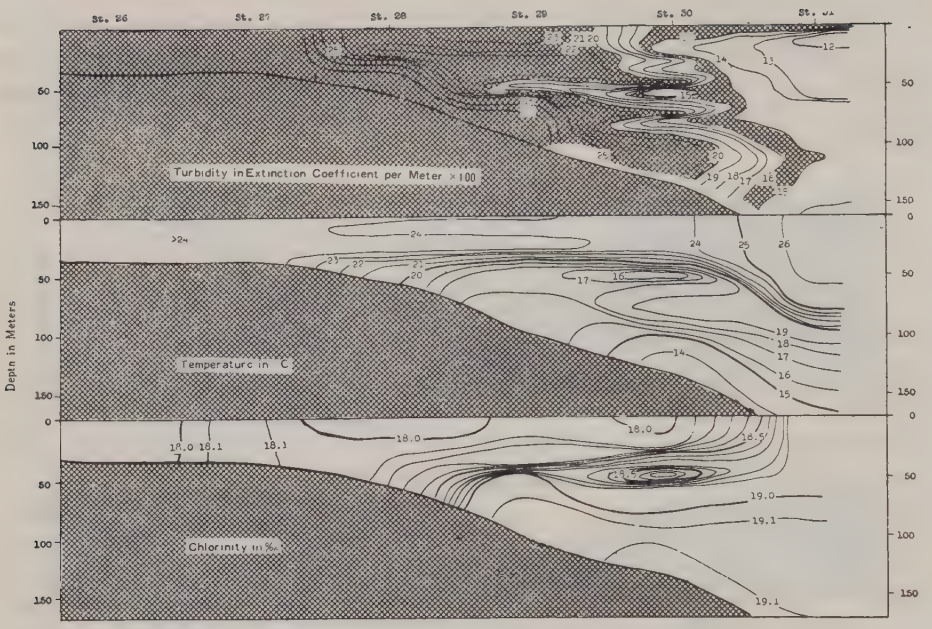


Fig. 10. Vertical distributions of turbidity, temperature and chlorinity at sections through stations 2 to 11 (upper), through stations 15 to 24 (lower) and through stations 26 to 31 (next page).



Discussion

The sensitivity of the present instrument is high enough to measure coastal water turbidity, but in oceanic regions a little higher sensitivity is desired. High sensitivity, however, requires high stability of the measuring circuit as well as the accurate and fine standardization of the optical system. In the present instrument, the standardization can be performed only when it is raised up on to the deck, and it is often disturbed by dirt and moisture on the two window glasses, which it is very difficult to wipe out completely on the deck. No color filter is used in this instrument to gain as high sensitivity as possible without amplified circuit, the purpose of the present observation being to measure approximate total suspended loads of sea water not including the gaining of informatoin on particle size of suspended materials.

Carefully distilled water is measured by this instrument to have a value of 0.05 in extinction coefficient per meter, and therefore, values resulting after subtraction of 0.05 from observed values are considered approximately proportional to the total suspended loads in the observed layers disregarding the effect of the particle size distribution.

That the turbidity is an excellent indicator of water mass has been ascertained by several workers. N. G. Jerlov (1951a, 1951b, 1951c and 1953) has succeeded by means of a Tyndall meter in establishing the significant role of the turbidity of sea water in the determination of water mass distribution in oceanic regions as well as in coastal regions. J. Joseph

(1949) designed a transparency meter which enables measurement of the transparency of sea water in the long wave ultra-violet region of the spectrum. He showed that the stratification of water in the sound off Copenhagen could be analysed by the extinction coefficient in the above mentioned region of the spectrum more distinctly than by temperature and salinity. A sharp maximum of turbidity was also found in the transition layer between the shallow Barents Sea water and cold bottom water from the North Sea. K. Wyrtki (1950) found the complex turbidity distribution in Kiel Bay, measured by the transparency meter designed by J. Joseph, to keep fairly good conformity to the fine oceanographic structure of the region. He confirmed that there occurred sudden increases of turbidity values between the surface homogeneous layer of low density and the dense bottom water, and that there are often formed characteristic turbidity maxima which "wandern langsam" through the boundary layer downwards until they vanish out into the turbid bottom water.

In the present observation the knees of turbidity are not always situated at the depth of maximum density gradient but are some ten meters deeper than the latter. Further, in most cases, immediately above the knees there are found distinct turbidity minima as at stations 10 and 21. The same minimum was found by K. Wyrtki in Kiel Bay and was explained as the remainder of a clear water that had occupied the shallow layer and had been displaced by a more turbid water which now occupied that layer. In fact, he found that the minimum disappeared in a few hours. In the present observation, however, the minimum layer is found in a vast area to the left side of the strong currents and the thickness of the layer is fairly great (about 20 m) covering the density spring layer. It is considered to be a kind of tongue-like distribution, which is brought about by horizontal and vertical mixing processes, for horizontal currents at the stable spring layer must be very small, according to the equation (Sverdrup et al. 1942)

$$\frac{Ax}{\rho}\frac{\partial^2 T}{\partial x^2}+\frac{Az}{\rho}\frac{\partial^2 T}{\partial Z^2}=0$$

where Tx is the turbidity, Ax and Az are the horizontal and vertical eddy diffusivity respectively, and ρ is the density of sea water. The horizontal mixing expressed by Ax is considered to be very high in the stable stratification at the spring layer (A. E. Parr, 1936). The minimum of turbidity is therefore always found at the maximum gradient of density and it maintains its existence almost stationary as clearly shown in Fig. 10. Consequently the knee of turbidity below the minimum is exaggeratedly sharp and depressed some distance down from the layer of maximum density gradient.

The suspended material of the water on the continental shelf of the Eastern China Sea is composed mainly of terrigeneous clay or detritus and

especially of bottom sediments stirred up from the bottom as suggested by the rapid increase of turbidity towards the bottom. The percentage of living phytoplankton is negligibly small. J. Krey (1954) analysed the water samples taken from the North Sea during the Gauss cruise in August 1952 and found that high concentrations of suspended particles occurred at the spring layer of temperature in the northern region of the Dogger Bank. The particles were mainly composed of suspended detritus; the percentage composition of living phyto-plankton was in most cases less than ten percent in the spring layer and outside the spring layer less than one percent in dry weight.

When the water considered is homogeneous in horizontal directions, the downward transport or flux F of the particles crossing a unit horizontal area due to sinking and diffusion is

$$F=Tv-\frac{A}{\rho}\frac{\partial T}{\partial Z}, \qquad (1)$$

where v is the sinking velocity of the particles, A is the vertical eddy dicusivity and T is the turbidity of water in extinction coefficient (after subtraction of 0.05 from the observed value). F must be zero when no organic production occurs and the process is considered to be stationary, that is

$$Tv-\frac{A}{\rho}\frac{\partial T}{\partial Z}=0 \qquad (2)$$

From this $$\frac{A}{\rho v}=T\Big/\frac{\partial T}{\partial Z}.$$

At station 9 where the above conditions are comparatively well fulfilled, the equation (2) is applied and A/v is calculated as shown in Fig. 11. If the sinking velocity is known, the values of vertical eddy diffusivity are obtained from this curve.

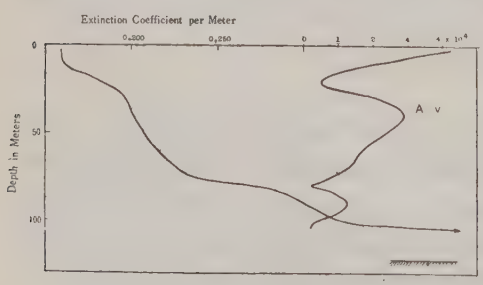


Fig. 11. Vertical distributions of turbidity and values A/v calculated according to the equation (2) at station 9.

In oceanic waters, production of organisms can not be neglected, the main source of suspended particles being considered to be phyto-plankton and its remnants (T. Tsujita, 1956). Z must be equal to the sum of the organiz production $R(Z)$ in the water organiz production $R(z)$ in the water column above z, namely

$$F=Tv-\frac{A}{\rho}\frac{\partial T}{\partial Z}=\int_0^z (Z)RdZ \qquad (3)$$

By differentiating the above equation,

$$\frac{\partial F}{\partial Z}=R \qquad (4)$$

is obtained. The distribution of turbidity in the oceanic region to the right of the Kuroshio axis (stations 5 and 6) is considered to be little influenced by bottom sediments, and if the stationary state is assumed for the distribution, the downward flux of susended material and the organic production at each level can be calculated provided that the sinking velocity v and the vertical diffusivity A in the region are known. The result of an attempt at such calculation is given in Fig. 12 in which the vertical eddy diffusivity is assumed according to the formula presented by W. H. Munk and E. R. Anderson (1948)

$$A=A_0(1+\beta r)^{-\frac{3}{2}} \qquad (5)$$

where A_0 is the value of A in the case of neutral stability, β is the constant 3.33 and r is the Richardson's number defined by

$$r=\frac{g\frac{\partial \rho}{\partial Z}}{\rho\left(\frac{\partial U}{\partial Z}\right)^2} \qquad (6)$$

in which ρ is the density of sea water, u is the horizontal current velocity and g is the gravitational acceleration. $\frac{\partial U}{\partial Z}$ is calculated from inclinations of isobaric surfaces. At the sea surface the downward flux must be zero and therefore the value of A/v at the sea surface is calculated from the vertical distribution of turbidity. And then A_0/v is obtained by inserting the surface value of each term into the equation (5). The relative values of two functions $F(Z)=Tv-\frac{A}{\rho}\frac{\partial T}{\partial Z}$ and $\frac{\partial F(Z)}{\partial Z}$ are thus determined without assuming any definite palue for the sinking velocity of suspended material. The curves shown in Fig. 12 is the results of calculation when v is assumed 3×10^{-3} cm/sec. Corresponding values of eddy diffusivity are calculated as follows: at the sea surface 468, at 10 m depth 1.3, between 20 and 30 m below 1, between 60 and 100 m ranging 1 to 5, between 110 and 120 m below 1 and down from 130 m again above 1 but below 4, mean value being 35 in g/cm/sec. These values are of the same order to but are slightly too low in comparison to the values obtained by G. A. Riley et al. (1949) in the Gulf Stream off New England from the observation of seasonal temperature changes in May. By the same authors the minimum value of sinking velocity for phyto-plankton population in the oceanic Atlantic waters was calculated from the theoretical consideration of vertical phyto-plankton distribution to be 2.9×10^{-3} cm/sec corresponding to the

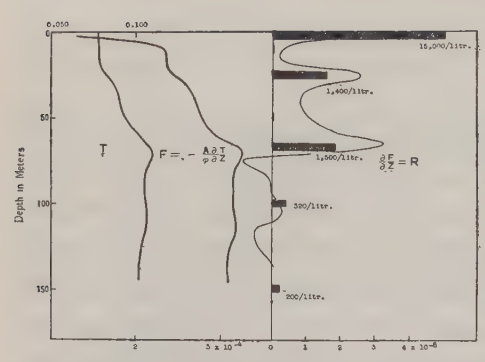


Fig. 12. Mean vertical distributions of turbidity in the oceanic homegeneous water to the right of the Kuroshio axis (at stations 5 and 6), downward transport of suspended particles and production of particles, the latter two being calculated from the distribution of turbidity according to the equations (3) and (4) respectively. Phyto-plankton crop sampled at the same time with the turbidity measurement is also illustrated.

minimum limit of vertical diffusivity of 40 g/cm/sec averaged through shallow layer down to 200 m depth. It is reasonable to assume that the sinking velocity of suspended particles including a large part of planktonic detritus and a small part of living phyto-plankton is a little higher than that of pure phyto-plankton population. It may be higher than 3×10^{-3} cm/sec and correspondingly the eddy diffucivity may be a little higher than the values calculated above.

The organic production R is proportional to the standing crop P, namely

$$R=\omega P \qquad (7)$$

where ω is the phyto-plankton production rate. The values of ω is zero below euphotic layer, and at the surface it is generally smaller than in the middepths (G. A. Riley et al., 1949). Individual numbers of phyto-plankton at several depths sampled at the same time as the turbidity measurement are also indicated in Fig. 12. The curve $\frac{\partial F}{\partial Z}$ corresponds in fairly good approximation to the vertical distribution of phyto-plankton production ωP. This result ascertains the assumption that the suspended detritus comes mainly from the disintegration of phyto-plankton remains.

Negative values of $\frac{\partial F}{\partial Z}$ found at 75 m depth and 120 m depth may perhaps indicate negative rates of plankton production or decomposition of sinking detritus at such layers if the assumption of stationary state is admitted for the vertical distribution of turbidity. These problems will be clarified if a continous measurement of turbidity over a period at least a week or more is performed together with the direct measurement of plankton productivity by some method such as the fixation of radioactive carbon dioxide.

It is a pleasure to record here a debt of gratitude to Professor S. Motoda of the Faculty of Fisheries, Hokkaido University for his cordial

supporting of the present work and valuable advices during the investigation. The authors are much indebted to Dr. T. Tsujita of the Saikai Regional Fisheries Laboratory for his generosity in providing many facilities during the observation cruise and especially for permission of free use of oceanographical data obtained in the present cruise. Particular thanks are due to Dr. T. Kawamura of the Faculty who kindly undertook to count individual numbers of phyto-plankton. They also wishes to express their thanks to Mr. M. Anraku of the Faculty for his kind help in the laborious work at sea.

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March 1958

A SUBMERSIBLE TURBIDIMETER

By
Tadayoshi Sasaki,* Gohachirō Ōshiba,**
Seiichi Watanabe** and Noboru Okami**

Introduction

Many types of submersible turbidimeter for various purposes have hitherto been made and there have been a lot of reports on the results using the instruments and we have also made a submersible turbidimeter for measuring high turbidity in waters such as artificial lakes and reported the results using our instrument.[1)]

Now we make another submersible turbidimeter for measuring turbidity at depths up to 100 meters in order to investigate optical characters of seawaters which have an intimate relation to marine creatures, and report the results of the experiments using this new instrument.

The new turbidimeter has been constructed so as to measure medium turbidity of seawaters, which has a wide range.

Explanation and operation of the apparatus

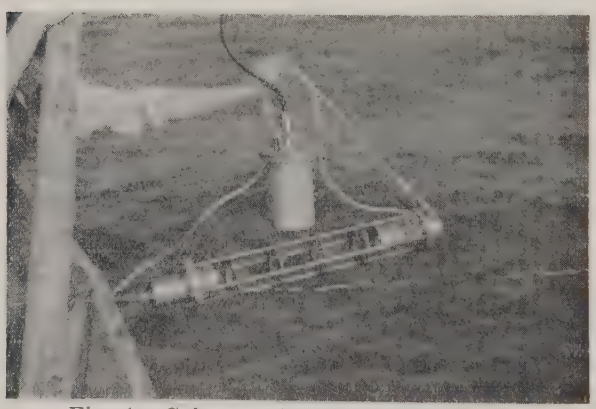

Fig. 1. Submerged unit before lowering.

Using this turbidimeter tubidity is determined by measuring the grade of parallel beams from a lamp of constant intensity shining through 500 mm thickness of seawater to be tested and being decreased by absorption and scattering. It consists of the submerged unit, the deck unit and the 3-core cabtyre-cable having an outside diameter

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1) J. Sci. Res. Inst., 31 (1955), 18. (in Japanese).

of 14 mm and length of 120 meters.

The submerged unit consists of three portions, the first portion, where the lamp is placed, the second portion, where light is received, and the third portion, from which electric current for lamp is supplied. Fig. 1 shows the lowering submerged unit and Fig. 2 shows the diagram of it.

The first portion is a water-tight cylinder having a diameter of 75 mm and a length of 200 mm, in which the lamp (4V, 1A) for light source, optical section and the control photronic cell are situated.

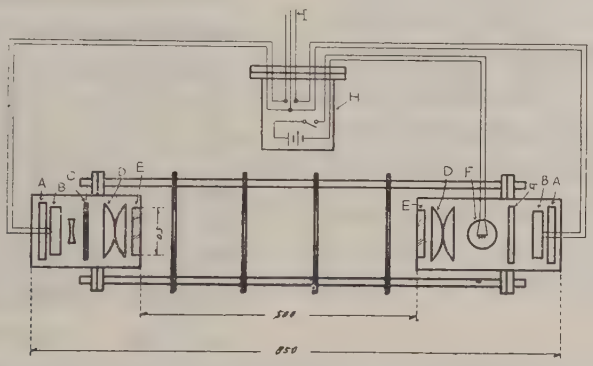

Fig. 2. Diagram showing components in submerged unit.
A....drier B....photronic cell C....slit D....lenses E....glass window F....lamp G....heat-absorbing glass H....water-tight battery and junction box I....3-core cabtyre-cable

The second portion is also a water-tight cylinder having a diameter of 75 mm and a length of 160 mm, in which the reference photronic cell, a series of lenses are situated. The surface of photronic cell receives only parallel beams from the lamp. Some drier is put into the first and second portions so as to keep the insulation of terminals of the photronic cells.

The first and the second portions are assembled by four bars having a diameter of 10 mm each and all the three portions are deviced so as to plunge into seawater. The four bars are strengthened by four disks placed at a same distance, each of which has a diameter of 120 mm and a hole having a diameter of 50 mm in center.

The third portion is a water-tight cylinder having a diameter of 110 mm and a height of 210 mm, in which two batteries (2V, 10AH) and a switch for electric current, which may be operated from outside. The top of the cylinder has three water-tight cable-entries through which three 2-core cables (diameter: 8 mm) from the first and the second portions are introduced into the cylinder. A water-tight connector-socket

connecting 3-core cabtyre-cable is placed in the center of the top. The water-tight plug of the cabtyre-cable is put into the socket before measurement.

Fig. 3 shows the circuit of the deck unit. The control and reference phtotronic cells are connected to the bridge-circuit and this is introduced to the vacuum tube voltmeter and the resistance beside the control photornic cell is adjusted so as to obtain a balanced point. Then the submerged unit is connected to the deck unit by the 3-core cabtyre-cable at the connector and the switch in the third portion and the switch S_2 in the deck unit shown in Fig. 3 are closed and the submerged unit is lowered by the lope into seawater at a voluntary depth. The switch S_1 is closed and the variable resistance R_2 is adjusted so as to place the pointer of the center-zero microammeter A accurately at the zero-point. And the switch S_1 is opened and the pointer leans to anyside. The variable resistance R_1 is adjusted till the pointer indicates the zero-point again and the dial is read. The value is corrected by the table and the percentage transmittancy or optical dnsity is determined.

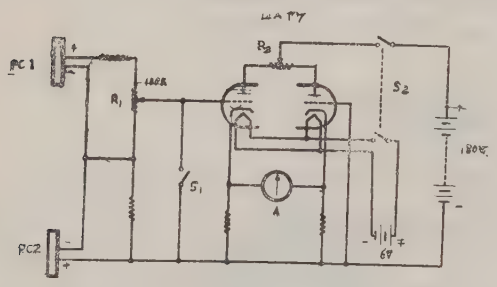

Fig. 3. Circuit diagram of the deck unit.

Each photronic cell made by SAF Co. in West Germany has a light receiving area having a diameter of 40 mm.

Correction is carried out as follows: the submerged unit is soaked into a water-tank containing distilled water and a few neutral density filters having various transmittances are inserted one by one in front of the second portion and the dial is read in each case. A correction curve is made from dial readings and percentage transmittancy or optical density.

Example

Fig. 4 shows the vertical distributions of percentage transmittancy in seawaters near Itō-haver and off Usami in Shizuoka Prefecture. The investigation was carried out in October, 1956. The seawaters have considerable turbidity on account of river Matsukawa which empties into the sea at Itō.

In Fig. 4 St. 1 lies 180 m northeast of the mouth of river Matsukawa, at which the sea is 6 m deep; St. 2 lies 370 m northeast of the mouth, at

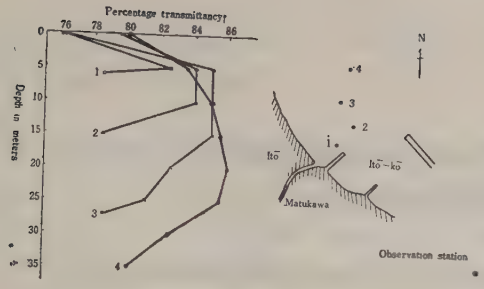

Fig. 4. Vertical distributions of turbidity at near Itō-harbor in Shizuoka Prefecture.

which the sea is 15 m deep; St. 3 lies about 930 m northnortheast of the mouth, at which the sea is 35 m deep. The bottom of the investigated area is soft mud or sandy mud. The temperature of the surface of the area is 16°C, while that of the seawater far off the coast is 22°C. The temperature of the surface of the investigated area is somewhat decreased by flowing water of river Matsukawa.

From the curve shown in Fig. 4 we can see that the waters of the surface and near the bottom are considerably turbid, but relatively transparent seawater flows into the middle layer.

From the data shown in Fig. 4 we conclude that the newly made instrument is useful for investigation in situ.

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SPECTRAL ENERGY DISTRIBUTION OF SUBMARINE DAYLIGHT OFF KII PENINSULA

—In Relation to the Investigation of Oceanic Productivity—

By Tadayoshi Sasaki,* Noboru Okami,**
Gohachirō Ōshiba** and Seiichi Watanabe**

Introduction

In the case of estimating the basic production of seawater it is necessary to know the effective energy of submarine daylight which transmits euphotic zone and becomes one of main environmental factors of photosynthesis by phytoplankton.

If the absorption coefficient by phytoplankton of radiant energy in various wave-lengths is known the effective energy used for photosynthesis at any voluntary depth can be calculated from the absorption coefficient and the spectral energy distribution. But until the relationship between the rate of photosynthesis and radiant energy at different wave-length becomes accurately explanable, total energy in the energy spectrum of submarine daylight or that of visible part only should be adopted as effective energy.

So if spectral energy distribution of submarine daylight is known, the effective energy at any given depth can be obtained by calculating the area enclosed between base line and the curve of spectral energy distribution which is expressed in absolute values. When using radiometric units the effective energy is expressed in ergs per unit surface and unit time, for example, ergs/cm^2/sec or g•cal/cm^2/hour.

Among a lot of reports on photosynthesis by plankton, which have already been published, there are some reports that effective radiant flux is limited to luminous flux and effective energy is expressed in Lux, unit of illumination. For the purpose of comparing our data with those of the reports previously published it is necessary to express the results of measuring daylight by two units, radiometric and photometric.

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There is no simple formula, which is useful on the spot, between these two units. If the spectral energy distribution (absolute values) is known illumination is calculated from this distribution and the absolute luminosity.

In relation to the investigation of oceanic productivity in the circumference of Kii Peninsula, the measurement of daylight in the sea was carried out in November 1956 at several stations off the Peninsula. By the data of the observations spectral energy distribution within the range of wave-lengths from 400 mμ to 700 mμ at several depths at each station is determined. Using the spectral energy distribution value of energy in the visible part of spectrum incident on the horizontal surface and illumination at different depths are calculated.

Spectral energy distribution

The relative energy distribution of the daylight incident on the surface of the sea is assumed entirely same as that measured in Cleveland by A. H. Taylor[1] on clear and cloudy days.

If the absolute value of the spectral energy distribution of daylight incident on the unit area of the surface of the sea is P_λ, the illumination E of the surface is expressed in the following equation.

$$E=K_m\int_0^\infty P_\lambda \cdot V_\lambda \cdot d\lambda \quad \cdots\cdots(1)$$

where K_m is the maximum luminous efficiency of radiant flux and V_λ is the standard luminosity data.

If the maximum value of spectral energy distribution is P_m and the relative value is p_λ following equation is formed,

$$P_\lambda = P_m \cdot p_\lambda \quad \cdots\cdots(2)$$

therefor Equation (1) can be changed into following equation.

$$P_m = \frac{E}{K_m\int_0^\infty p_\lambda \cdot V_\lambda \cdot d\lambda} \quad \cdots\cdots(3)$$

If $\int_0^\infty p_\lambda \cdot V_\lambda \cdot d\lambda \fallingdotseq \int_{400m\mu}^{700m\mu} p_\lambda \cdot V_\lambda \cdot d\lambda$ and using $K_m=650$ lumens/Watt determined by I.C.I. and the standard luminosity data V_λ (relative values)[2] from Taylor's relative spectral energy distribution $\int_{400m\mu}^{700m\mu} p_\lambda \cdot V_\lambda \cdot d\lambda$ on clear and cloudy days respectively is previously caliculated, the spectral energy distribution expressed in absolute value of daylight incident on the surface of

1) A. H. Taylor and G. P. Kerr: J. Opt. Soc. Amer., 31 (1941), 3.

2) Reports of the Committee on Colorimetry, J. Opt. Soc. Amer., 31 (1944), 633.

the sea in situ can be deduced using Equations (2) and (3).

The illumination photometer for measuring the surface illumination of the sea consists of a light receiver and indicators. The light receiver consists of an opal glass used as light receiving surface, nutral density filter, a filter for correction of luminous efficiency, and photronic cell. The calibration of this photometer is carried out to compare with the Matsuda No. 5 Luxmeter using the direct rays of the sun as light source. By changing several nutral density filters for each other illumination of range from 0 to 10^5 Lux can be measured. The receiver is placed on a gimbal on board a ship.

Considering the decreasement of spectral energy distribution by reflection from the surface of the sea the spectral energy distribution of daylight through the surface of the sea is calculated. Assuming that the spectral reflectance used in calculation is constant within the range of wave-lengths from 400m μ to 700mμ, and being referred to the theoretical values by H.U. Sverdrop et al.[3] and the experimental values measured by E.O. Hulburt[4] in Chesapeake Bay the spectral reflectance is deduced.

In order to determine the spectral energy distribution of daylight incident on the horizontal planes at different depths of the sea, the measurement in situ is carried out by means of a submarine photometer[5] to which five color filters are attached, and extinction coefficient of spectral energy composition in center of the gravity λ_m (shown in Table 1) of the spectral

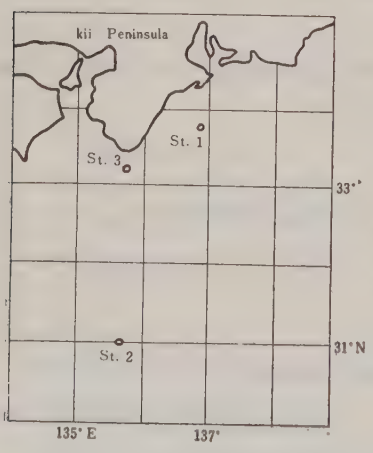

Fig. 1. Location of stations where observations were made.

Table 1. The range of wave-length of the spectral sensitivity combined with color filters and photronic cell, and center of gravity λ_m.

Filter	Range of wave-length	Center of gravity λ_m
V	380mμ—510mμ	445mμ
B	390mμ—550mμ	470mμ
G	480mμ—600mμ	525mμ
Y	560mμ—660mμ	580mμ
R	610mμ—700mμ	645mμ

3) H. U. Sverdrop et al.: The Oceans, Prentice-Holl, New York (1949), 104.
4) E. O. Hulburt: J. Opt. Soc. Amer., 35 (1945), 698.
5) T. Sasaki et al.: Records of Oceano. Works in Japan, 2 1955), 1.

sensitivity curve made by the photronic cell combined with each filter, is determined. From the extinction coefficient and the spectral energy composition of the same wave-lengths at the depth of 0 m already calculated, the spectral energy composition at each depth, where measurement is done, is calculated. The spectral energy composition of other wave-lengths is determined by interpolation among the values of spectral composition of these five wave-lengths. The spectral energy composition at each depth calculated by the method described above is expressed in unit radiant flux per unit area, $W/m^2/\mu$.

Observations and their results

The observations of daylight in the sea were carried out at the stations shown in Fig. 1 on November 18-20, 1956. The results are shown in Table 2, Figs. 2, 3 and 4.

The spectral energy distribution acquired from the results shown in Table 2 by the method described above is shown in Fig. 5. The reflectance used in calculation is 5.2% : the value was determined under the cloudy sky.

The spectral energy distribution at Station 3 is shown in Fig. 6. As with respect to red and yellow lights no measurement was carried out, the extinction coefficients of these two lights at Station 1 were used. The average altitude of the sun when observations were done was 34° 4% is

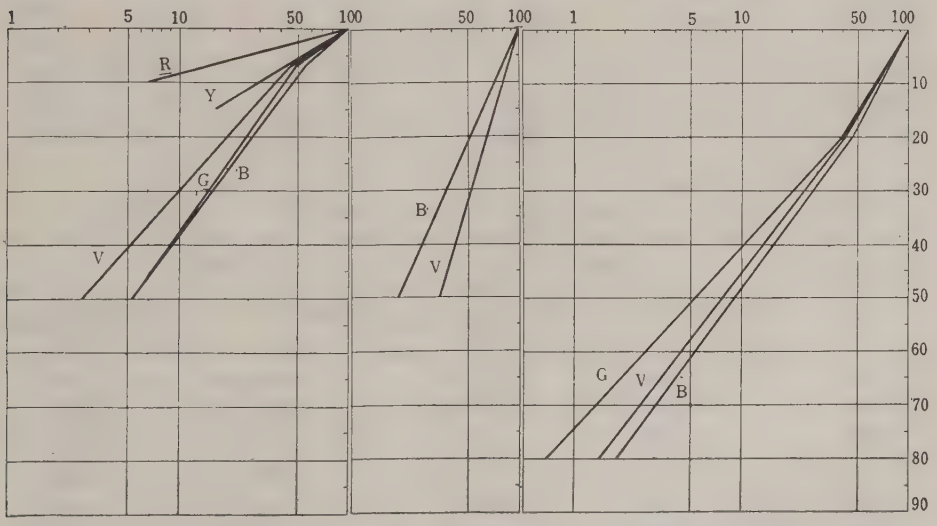

Fig. 2. Percentage of surface radiation at different depths for five color filters at Station 1.

Fig. 3. Percentage of surface radiation at different depths for two color filters at Station 2.

Fig. 4. Percentage of surface radiation of different depths for three color filters at Station 3.

Table 2. Summary of observations

Station	1	2	3
Latitude: N	33°—40.0′	31°—00.0′	33°—20.0′
Longitude: E	136°—50.0′	135°—40.0′	135°—40.0′
Date : 1956	Nov. 18	Nov. 19	Nov. 20
Local Time	1132—1233	1135—1200	1135—1225
Sea	1	2	2
Sky	overcast	overcast	clear
Altitude of sun	—	—	32°23′—35°57′
Illumination	8300 Lux		49000 Lux
Red light (R)			
Extinction coefficient (m^{-1})	0—10m : 0.275	—	—
Yellow light (Y)			
Extinction coefficient (m^{-1})	0—15m : 0.120	—	—
Green light (G)			
Extinction coefficient (m^{-1})	0— 7m : 0.104 7—50m : 0.051	—	0—20m : 0.044 20—80m : 0.068
Blue light (B)			
Extinction coefficient (m^{-1})	0— 7m : 0.087 7—50m : 0.054	0—50m : 0.033	0—20m : 0.037 20—80m : 0.054
Violet light (V)			
Extinction coefficient (m^{-1})	0— 7m : 0.112 7—50m : 0.066	0—50m : 0.023	0—20m : 0.044 20—80m : 0.056

Table 3. Values of mean vertical extinction coefficient at two stations.

Wave-length	Station 1		Station 3	
mμ	Range of depth m	Extinction coefficient m^{-1}	Range of depth m	Extinction coefficient m^{-1}
400	0—10	0.233	0—25	0.141
450	0—50	0.068	0—80	0.051
500	0—50	0.054	0—80	0.051
550	0—25	0.072	0—50	0.081
600	0—10	0.149	0—25	0.161
650	0—10	0.296	0—10	0.327
700	0— 5	0.401	0— 5	0.427

adopted as the reflectance on the surface of the sea.

The radiant energy from 400 mμ to 700 mμ incident on the unit area

Table 4. Values of energy in the visible part of spectrum (400 mμ—700 mμ) and illumination at different depths.

Depth m	Station 1		Station 3	
	Energy g·cal/cm²/hour	Illumination Lux	Energy g·cal/cm²/hour	Ielumination Lux
0	3.46	9153	17.5	47995
1	2.99	8297	15.2	43128
2	2.59	7504	13.3	38404
5	1.84	5699	9.59	28883
10	1.17	3797	6.29	18947
25	0.39	1260	2.29	5916
50	0.078	240	0.533	1116
100	0.036	8	0.039	64.5

Table 5. Percentage amounts of energy in the visible part of spectrum (400 mμ—700 mμ) at different depths and extinction coefficients of energy in different intervals of depth.

Depth m	Percentage amounts of incident energy		Interval of depth m	Extinction coefficients m^{-1}	
	St. 1	St. 3		St. 1	St. 3
0	100	100	0— 1	0.146	0.143
1	86.4	86.8	1— 2	0.143	0.133
2	74.9	75.9	2— 5	0.114	0.109
5	53.2	54.7	5— 10	0.090	0.084
10	33.9	35.9	10— 25	0.073	0.067
25	11.3	13.0	25— 50	0.063	0.058
50	2.3	3.04	50—100	0.063	0.052
100	0.1	0.23			

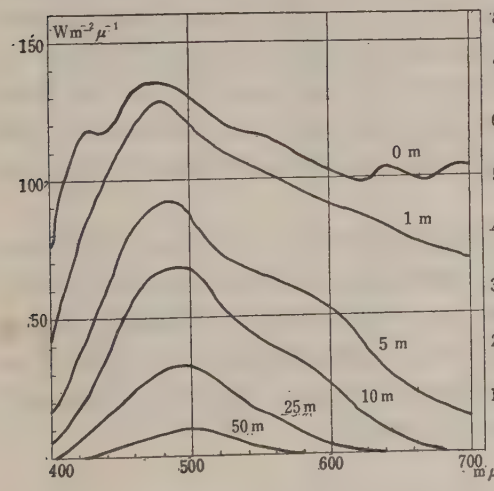

Fig. 5. Spectral energy distributions at station 1.

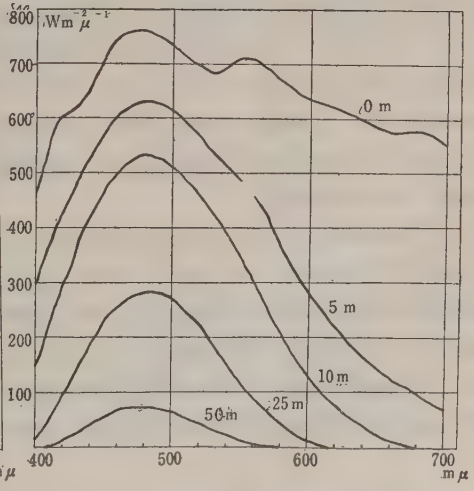

Fig. 6. Spectral energy distributions at station 3.

Table 6. Percentage amounts of illumination at different depths and extinction coefficients of illumination in different intervals of depth.

Depth	Percentage amounts of surface illumination		Intervals of depth	Extinction coefficient m^{-1}	
m	St. 1	St. 3	m	St. 1	St. 3
0	100	100	0— 1	0.103	0.106
1	90.6	89.9	1— 2	0.095	0.117
2	82.0	80.0	2— 5	0.091	0.095
5	62.3	60.2	5— 10	0.081	0.084
10	41.5	39.5	10— 25	0.073	0.078
25	13.8	12.3	25— 50	0.066	0.066
50	2.62	2.33	50—100	0.067	0.058
100	0.09	0.13			

of the horizontal plane and illumination at different depths at the time when observation were done, can be directly calculated using the spectral distributin of radiant energy at Stations 1 and 3 shown in Figs. 5 and 6 But values shown in Table 4 are calculated at southing.

The illuminations at southing on November 18-20 observed by the illumination photometer on board a ship were 9,600 Lux and 50,000 Lux respectively. These values found on board of sailing ship are not exactly the same values of illumination at Stations 1 and 3 at southing, but the calculation was done using these measured values must be near the exact values.

The extinction coefficient at each wave-length used in calculation of daylight incident on the seawater is mean value and shown in Table 3. These values are obtained from Figs. 5 and 6 by the method same as that of N. G. Jerlov[6], assuming the optical properties of seawater in the region, where observations were carried out, to be homogeneous in the vertical direction. Using these mean extinction coefficients, the change of the extinction coefficients near the surface of the sea by the altitude of the sun may be averaged.

The energy and illumination at different depths are expressed in Tables 5 and 6 in which are shown extinction coefficients of the energy and illumination in different intervals of depth too. As shown in Tables 5 and 6 there is no great difference between values at Stations 1 and 2. The data in Tables 4~6 will be useful for knowing the average values of energy and illumination on clear and cloudy day in November.

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6) N. G. Jerlov: Reports of the Swedish Deep-Sea Expedition 3 (1951).

Summary

It is desirable to divide the range of wave-lengths into as many portions as possible by means of a number of color filters, when the submarine photometer is used in order to find the spectral energy distribution of daylight incident on every layer in the sea. The spectral energy distribution is found from the results of the observations using five color filters off Kii Peninsula. From this spectral energy distribution radiant energy incident on the horizontal plane of each layer in the sea where measurement is done in the range of wave-lengths from 400 mμ to 700 mμ and illumination are calculated. The values of energy expressed in absolute value found by calculation are the values within the visible part and therefore relatively small compared with those near the surface of the sea in the whole range of wave-lengths. But in deeper layers the spectral energy distribution in the whole range of wave-lengths consists most of that within the visible part and these two values are quite same.

The data which the authors have acquired will be useful for knowing effective energy necessary to photosynthesis by some of phytoplankton.

Acknowledgement

The authors wish to express their hearty thanks to Dr. Y. Shibata, Director of Kobe Marine Observatory and Dr. Y. Takenouchi, Central Meteological Observatory who gave us a chance to embark in the observation ship Shunpu-Maru and Mr. H. Kawaike, captain of the ship and Mr. S. Moriyasu and other observers of Kobe Marine Observatory. The authors are also thankful to favors of Dr. Y. Miyake and Mr. Y. Sugiura of the Meteological Research Institute and Mr. K. Kameda of the Japan Atomic Energy Research Institute.

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FLUCTUATIONS IN THE FISHERY FOR YOUNG SARDINE OFF SHICHIRI-MIHAMA, KII PENINSULA*

One of the Data Relevant to Fluctuations of the Sardine Stock in Japanese Waters

By Ziniziro Nakai

(Tokai Regional Fisheries Research Laboratory)

Introduction

In an area south off Kii Peninsula a cold water mass prevailed with the years 1938 to 1941 as its most developed period. The phenomenon, as it was located off a cape, Shiono-misaki, was known to the people concerned as the "cold water mass off Shiono-misaki" and regarded from its expansive scale as one of the most remarkable oceanographic anomalies that had ever occurred along the Kuroshio adjacent to Japan (Uda, 1940, 1949, 1951). According to an inference proposed by Nakai (1943, 1949, 1955), this anomaly of the Kuroshio was responsible as an initial factor for a critical decrease in the catch of the Japanese sardine *Sardinops melanosticta* (Temminck et Schlegel) which began to affect sardine fisheries of the country about 1942. His inference has been based on the following.

1) In those days, a majority of sardine eggs that were born during February to March in the sea of Satsu'nan Region, the then main spawning ground for the fish off the southern tip of Kyushu, used to be transported northeastward by the Kuroshio along the Pacific coast. However, it is almost certain that the hydrographic anomaly described above impaired numbers of the developing fish larvae which were drifted to the area on their way to the northeastern destination. This is believed to have set off the initial cause of depletion in the sardine stock that took place in the Japanese waters in the recent years.

2) The decrease in the abundance, consequently, induced a

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* Contribution B-281 from the Tokai Regional Fisheries Research Laboratory.

change in the migratory route of the fish, with the spawning ground receding back little by little to the northwestern water off Kyushu and further to the western section of the Japan Sea. Whereas, almost all sardines ceased to come and spawn in Satsu'nan Region soon after the end of World War II.

3) Those circumstances have been persisting till now when there no longer exists the cold water mass off Shiono-misaki at all. However, it is inferable that the circumstances thus created intercepted the supply of sardine eggs and larvae to the Pacific water, inhibited this part of the ocean from contributing to the production as the major nursery ground for the Japanese sardine as it had done, and formed the secondary cause for depletion of the sardine stock. The effect was so decisive and so far-reaching as it has led the sardine fisheries on the Pacific coast to a virtual catastrophe and made it difficult for the nation's sardine stock to recover its former prosperity.

If the above inference is valid, the catch of young sardine in the neighbourhoods of Kii Peninsula, particularly in the east of Shiono-misaki, must have been abated in a close association with the oceanographic anomaly of the Kuroshio; the decrease in the local catch must have started around 1939-41 when the cold water prevailed there, then become more fatal to the fishery from 1946-47 onward, sharply reflecting the barren situation of Satsu'nan Region where the parent fish almost ceased to come and spawn. Again if these suppositions were really what happened then and there, they may possibly provide circumstantial evidences for the cause of adversity felt for years in the Japanese sardine fishery.

In an attempt at ascertaining whether or not there were such coincidences as advanced above by examining records of the local fishery for young sardine in those day, the author made field surveys at fishing villages on the Peninsula some years ago. Unfortunately, however, his attempt failed that time. One of the difficulties in obtaining first-hand information needed for the study consisted in a fact that most of documents kept by fishermen, their cooperatives or county offices had been lost in great "tsunamis", destructive waves caused by earthquakes that twice inundated the coastal area of the Peninsula, first on February 7, 1944, then on December 21, 1946*. Another impediment has been related with the fishery of the community as well as with the vernacular names of the

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* On the day in 1944, the waves reached a height of 6 m. at Owase, and in 1946, 6.6 m. at Fukuro. (Almanac of Physical Science, 1952. Tokyo Meteor. Obs. 1951).

young sardine; existence of the fishery should have been earlier brought out of obscurity but for its operation on a small scale; the young sardine should have been known as such but for their names unfamiliar to the public.

More recently, however, in 1957, field surveys with the same aim as before were undertaken for the second time and succeeded in obtaining an amount of pertinent data, on which basis the present account has been prepared. The surveys were conducted as one of research projects in regard to productivity of the ocean and its utilization entrusted to the Japan Society for the Promotion of Science by the Japanese National Commission for UNESCO.

Here the author expresses his deep gratitude to Mr. Araya of the Society who gave him an opportunity of carrying out the present study. Earnest cooperations rendered on the occasion of the field surveys by the various people of the villages and Mr. Shigemasa Hattori, member of the Tokai Regional Fisheries Laboratory, are highly appreciated, as well.

Material and Method

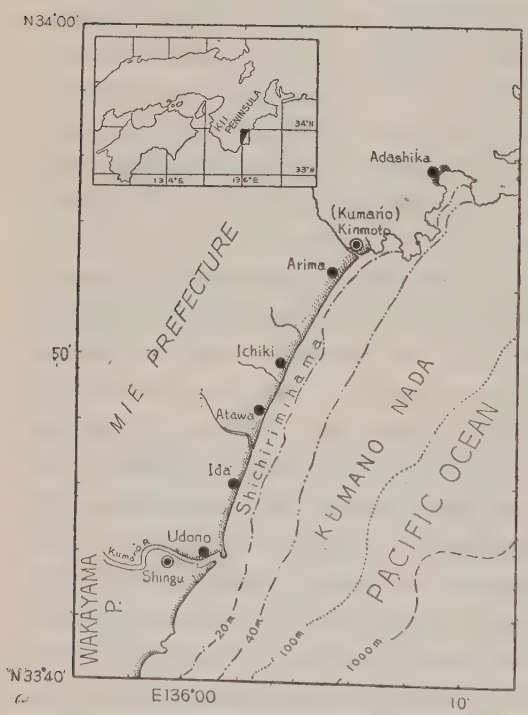

Fig. 1. Shichiri-Mihama and the neighborhoods.

The area covered by the surveys is located on the southeastern coast of Kii Peninsula, known as Shichiri-mihama, comprising fishing villages such as Kinomoto, Arima, Atawa, Ida and Udono (fig. 1). The sandy beach with shallow water extending some 20 kilometers between both ends, Kinomoto and Udono, has furnished the local community with favorable fishing conditions for beach seine operation since years back.

According to a statistical record (Bureau of Agr., Minis. Agr. Commer., 1892), the number of licensed beach seines in the community was 26 with the distribution by village as follows:

Udono	1	Arima	6
Ida	6	Kinomoto	3
Atawa	6	Adashika	1
Ichiki	3	Total	26

It is said that the number of nets and their distributions shown above have remained almost the same for more than half a century.

At the villages visited, interviews have been held with experienced fishermen and directors of fisheries cooperatives, while landing records and alike documents sought at their offices in the hope of securing information available for any conclusion. But the only materials that had been left intact from the "tsunamis" mentioned above and thus obtained so far were

A: landing book by a fisherman of Ida for one unit of seine, with entry for about seven years from May 6, 1925 to June 11, 1927 and May 18, 1940 to May 6, 1944;

B: register of landings by the Ida Fishermen's Cooperative for five seines for some six years from January 1944 to October 1949.

As is seen above, no trace of accounts had been left for the period 1928-39. Different vernacular names of fish which were made entry in the records depending on the size or developmental stage include "shirasu", larvae; "kaeri", juvenile; "kobira" specified below and "iwashi" or "yuwashi", adult; the last one being part of a compound word commonly applied to sardine; anchovy, *Engraulis japonica* (Houttuyn); and round herring, *Etrumeus micropus* (Temminck et Schlegel). Since they all but "kobira" were recorded irrespectively of the above three species, no breakdown of landings by species is possible except for "kobira", the name which is used only in this region specifically for the young sardine in a stage immediately after the metamorphosis from "karei", with the body length approximating 4-8 cm. For this reason, the examination in the forthcoming section will be made, for the time being, in pursuance of landings of the "kobira" alone.

Here it may be worth noting that these fishermen call sardine larvae "aoko" or "akahara" to distinguish them from "shirasu" by which they refer to anchovy larvae. The usage is also limited only to this region though no sardine larvae have been made entry under either name, however. Furthermore, these people used to call the anchovy "maiwashi" despite the latter denoting the sardine in all other parts of the country. Therefore it is very doubtful if they have ever identified the "kobira" in association with the "maiwashi" generally accepted for the sardine in Japan. An earlier discovery of the significant existence of beach seine fishery for young sardine off Shichiri-mihama should have been possible and likely led to substantial accounts of this particular type of fishing but for such an unusual nomenclature and the confusion involved therein.

Immigratory Season

Table 1 has been prepared on the basis of the materials A and B. It indicates the number of beach seining days by month operated for "kobira" by one unit of seine for the years prior to 1944, and by five units for the ensuing period, together with other pertinent information. Except for the months January to April 1925 and 1940 showing no data, the number of fishing days tabulated here seems to be nearly integral. Before 1946, according to the table, the fishing season or the months comprising successful days with any amount of yield was exclusively confined to April and May with the earliest gainful day having taken place on April 12, 1926, while the latest on May 29, 1940, save June 1925 when only one day had a yield. Since the locality of the fishing

Table 1. Number of Days Operated or Succeeded in Beach Seining for "Kobira".

Year		Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Fishing Began	Season Ended	Number of nets
1925	O	—	—	—	—	3*	1	0	1	1	2	10	16	May 6*	June 21	1
	S	—	—	—	—	3	1	0	0	0	0	0	0			
1926	O	2*	2	14*	20	5*	0	5	5	0	7	13	6	Apr. 12	May 17	1
	S	0	0	0	3	3	0	0	0	0	0	0	0			
1927	O	8	6	7	15	7	3*	—	—	—	—	—	—	Apr. 19	May 21	1
	S	0	0	0	4	5	0	—	—	—	—	—	—			
		(No data available for the years 1928 to 1939.)														
1940	O	—	—	—	—	7	0	2	0	3	1	0	6	May 16*	May 29	1
	S	—	—	—	—	6	0	0	0	0	0	0	0			
1941	O	17	8	16*	20	11	2	0	5	6	8	9	11	Apr. 23	May 24	1
	S	0	0	0	2	1	0	0	0	0	0	0	0			
1942	O	10	9	1	10	13	4	0	0	6	13	17	22	——	——	1
	S	0	0	0	0	0	0	0	0	0	0	0	0			
1943	O	6	5	7	13	11	0	0	2	9	13	16	23	Apr. 15	Apr. 27	1
	S	0	0	0	11	0	0	0	0	0	0	0	0			
1944	TO	33	34	35	22	40	12	12	3	3	13	31	22	——	May 27	5
	TS	0	0	0	0	1	0	0	0	0	0	0	0			
1945	TO	0	2	45	42	33	0	0	5	13	0	22	25	Apr. 13	May 26	5
	TS	0	0	0	7	4	0	0	0	0	0	0	0			
1946	TO	30	12	0	11	0	2	0	4	6	5	27	14	——	——	5
	TS	0	0	0	0	0	0	0	0	0	0	0	0			
1947	TO	0	0	3	19	15	8	0	13	4	12	52	12	——	——	5
	TS	0	0	0	0	0	0	0	0	0	0	0	0			
1948	TO	29	4	3	3	3	2	0	5	5	33	16	23	——	——	5
	TS	0	0	0	0	0	0	0	0	0	0	0	0			
1949	TO	28	5	23	44	10	0	0	1	20	12	—	—	——	——	5
	TS	0	0	0	0	0	0	0	0	0	0	—	—			

—: No data available for the month.
*: Incomplete because of the records partly lost.
O: Number of days operated.
S: Number of days succeeded in fishing.
TO: Total number of days operated by the nets.
TS: Total number of days succeeded in fishing by the nets.

area, construction and efficiency of the beach seines are supposed to have remained the same throughout the periods under report, it may be reasonable to assume that the months of successful fishing represent the

Table 2—1. Daily Catch of "Kobira" Based on Document A

(Unit: Kan*)

Year	Date	Amount	Year	Date	Amount
1925	May 6	203	1940	May 16	45
	〃 20	83		〃 18	80
	〃 24	108		〃 19	41.5
	June 21	(56)		〃 20	43
	Annual total	450		〃 23	(36)
1926	April 12	49		〃 29	(42)
	〃 14	38.5		Annual total	287.5
	〃 27	195	1941	April 23	97.5
	May 4	14		〃 27	40
	〃 8	248		May 24	132.5
	〃 17	110		Annual total	270
	Annual total	654.5	1942	May—April	0
1927	April 19	78.5	1943	April 15	41
	〃 24	133.5		〃 16	185.5
	〃 25	45		〃 17	14
	〃 29	599.5		〃 20	270
	May 5	77.5		〃 21	53.5
	〃 6	68		〃 22	69.5
	〃 9	48		〃 23	107
	〃 16	196.5		〃 24	253.6
	〃 21	116		〃 25	190.8
	Annual total	1,342.5		〃 26	64.5
				〃 27	18.5
				Annual total	1,267.9

Table 2—2. Daily Catch of "Kobira" Based on Document B

(Unit: Kan*)

Year	Date	Various units of beach seine A	B	C	D	E	Total	Average
1944	May 27	—	—	—	26	—	26	26
Annual total		—	—	—	26	—	26	
1945	April 13	0	28	0	0	0	28	5.6
	〃 14	—	123	—	0	0	123	41.0
	〃 15	88.5	45.5	—	0	0	134	33.5
	〃 16	164.5	56	0	0	0	220.5	44.1
	〃 17	—	71.5	0	—	—	71.5	35.7
	May 7	34	0	—	—	—	34	17.0
	〃 18	0	—	327	—	—	327	163.5
	〃 26	0	108	—	0	0	108	27.0
Annual total		287	432	327	0	0	1,046	

* One kan is approximately 3.75 kilograms.

Numerals in parentheses indicate the amounts estimated by dividing the day's proceeds with the unit price on the nearest day.

—: No fishing was operated for the day.

season when the fish immigrated into the sea off this region. With the year of 1946 as a turn of the situation, however, the fishing, no matter how frequently operated, has never been successful. This, as will be discussed later in regard to annual fluctuations in the net-day-catch, emphatically points to a serious change that likely occurred in the immigration of the young sardine, at least, to the vicinity of Ida.

Table 2 shows the amount of daily catch of "kobira" in April and May of those years (May and June for 1925); table 3, date when the operation failed completely. In table 2 one may see that on each of fifteen days the catch per net amounted to 100 kan (approx. 375 kg.) or more, and on the other five days, over 200 kan. With the use of these numbers of lucrative days, figure 2 has been drawn to present frequency of the abundant catch by 10-day intervals in which the days of each prescribed category are combined together regardless the years. It may be interesting to note in the figure that the net-day-catch over 100 kan took place during 40 days from the middle of April and that the last ten days of April had most frequently (6 times) the prolific catch despite the lack of data for April in 1925 and 1940. The richest catch per net-day

Table 3. Date When All the Nets Failed to Fish "Kobira"

May	1925	(Fishing was successful every day when operated.)
April	1926	1, 2, 4, 5, 7, 8, 10, 13, 15—17, 20—23, 26, 28
May	〃	1, 2 (No records are available from 18 onward.)
April	1927	6—9, 17, 18, 20, 26—28, 30
May	〃	8
.....		(No data available for the years 1928 to 1939.)
May	1940	22
April	1941	1—3, 6—9, 11, 12, 15—17, 19, 20, 24—26, 28
May	〃	2, 6—8, 11, 12, 15, 20, 21, 25
April	1942	6, 8, 10, 14, 15, 17, 18, 23, 24, 26
May	〃	2, 5, 6, 13—18, 22—24, 31
April	1943	10, 11, 13
May	〃	1, 3—5, 7, 12, 13, 23, 27, 29, 30
April	1944	1, 14—17, 21—24, 27, 30
May	〃	1, 2, 6—9, 13, 14, 20—24, 26
April	1945	7, 8, 9, 12, 21, 22
May	〃	4—6, 10, 11, 17, 20, 24, 25, 27, 28, 31
April	1946	1, 2, 7, 8, 10, 15, 16, 18, 22
April	1947	4—7, 11, 13, 16, 18, 19, 29
May	〃	5, 6, 10, 13, 14, 20, 22, 24, 27, 29
April	1948	24, 30
May	〃	1, 5, 10
April	1949	2, 7, 13—18, 21, 22, 24—26, 28—30
May	〃	4—9, 15

that was yielded during the thirteen years under consideration was about 600 kan on April 29, 1927 (table 2). Although the data so far obtained may not be very convincing us of a trend in the fishing season, the years for which the data are almost integral can be divided into two subperiods; the earlier one for 1926-27, when the fishing was prolific not only in April but in May as well, and the later from 1941 onward in which the operation tended to be concentrated in April most probably beacuse of the number of the immigrants decreasing one year after another. Particularly in 1943 when the gainful day was oftener than in any other year, the fishing was focused on thirteen days ending in April 27 inclusive of two futile days, the fact being suggestive of a marked curtailment in the immigratory season.

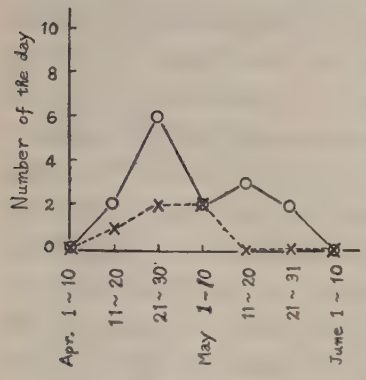

Fig. 2. Frequency of abundant catch of "kobira" by 10-day intervals. Beach seine at Ida-Mura, 1925-27 and 1940-45.

—o— Catch per net-day amounting more than 100 kan.

—x— Catch per net-day amounting more than 200 kan.

According to information given at the field interviews, the season for "kobira" belonged mostly to March and April, about a month earlier than those made entry in the landing books (see Appendix). The differences are likely attributable to inclusion by some of the fishermen in the season for "kobira" the months when the sardine larvae, "aoko" by the local name, or the juvenile, "kaeri", would make appearance to the region.

Annual Fluctuations in the Immigratory Amount

On the one hand, the present data consisting of one seine in material A and five in B, all belonging to a village, can never be warranted in perfectly representing the whole beach seines of the region numbering 26. On the other hand, topography of Shichiri-mihama as well as oceanographic conditions there is very simple; constructions of fishing gear were common among the villages with general landing trend differing little or not at all from place to place every year as far as stated by the interested parties. For these reasons, we may be justified here again, as before in discussing the immigratory season, to regard the present data as an index to fishing conditions of the region under study, while taking the above circumstances into account.

Before dealing with the annual fluctuations in the immigratory abundance on the basis of yield, changes, if any, in fishing efficiency during

the periods have to be considered. Nevertheless, as far as the period 1925-49 is concerned, there are reasons to believe that the efficiency remained nearly constant throughout the years. For the design and size of the beach seine in the region have been modified but little since 1920's up to now. Here it may be convenient to summarize specifications of gear and their changes on the basis of information that were given by the fishermen and will appear in Appendix. Until 1927 or so the so-called "genuine net" made of cotton or hemp had been in service for the wing. Then the material was substituted with rice straw. The length of the wing was 200-300 ken on each side (1 ken approx. 1.5 meters in the fishery denomination). More recently, since "kobira" were lost sight of, some of the fishermen extended their wing net for a length of about 500 ken on each side to operate for anchovy. The bag, made of cotton net, 9 piles, 25 stretch knots per unit length of *c.a.* 15 cm., or spliced net, had a length from mouth to cod-end of 15-25 ken.

Based on the landings by one seine prior to 1944 and by five there-

Table 4. Monthly Catch of "Kobira" and Catch per Net-Day
(Unit: Kan)

Year	Catch by month			Annual	Catch per net-day				Number
	April	May	June	total	April	May	June	Average	of nets
1925	—	394	56	450	—	131	56	112	1
1926	283	372	0	655	14	74	0	26	1
1927	837	506	0	1,343	55	72	0	61	1
—	(No data available for the years 1928 to 1939.)								
1940	—	288	0	288	—	41	0	41	1
1941	138	133	0	271	7	12	0	9	1
1942	0	0	0	0	0	0	0	0	1
1943	1,268	0	0	1,268	91	0	0	51	1
1944	0	26	0	26	0	0.6	0	0.4	5
1945	577	469	0	1,046	14	14	0	14	5
1946	0	0	0	0	0	0	0	0	5
1947	0	0	0	0	0	0	0	0	5
1948	0	0	0	0	0	0	0	0	5
1949	0	0	0	0	0	0	0	0	5

Note: 1. Up to the present (1957) no catch has been made since 1950, either.
2. Catch per net-day has been computed for 1925 by

$$\frac{\text{total catch in the season}}{\text{number of days operated in May and June,}}$$

for the other years, by

$$\frac{\text{total catch in the season}}{\text{number of days operated in April and May,}}$$

and for the years 1944 onwards, by

$$\frac{\text{total catch in the season}}{\text{number of days operated by all the nets.}}$$

3. One kan is approximately 3.75 kilograms.

Table 5. Frequency of "Kobira" Fishing by Weight-Intervals of Catch per Unit Effort in April and May

Weight-intervals of catch per unit effort (Kan*)	1925—27 period Frequency	%	1940—45 period Frequency	%	1946—49 period Frequency	%
0	32	62.7	191	85.5	105	100.0
1— 50	5	9.8	18	8.1	0	
51—100	5	9.8	6	2.7	0	
101—150	4	7.8	2	0.9	0	
151—200	2	3.9	4	1.8	0	
201—250	2	3.9	0	0	0	
251—300	0	0	2	0.9	0	
301—350	0	0	0	0	0	
351—400	0	0	0	0	0	
401—450	0	0	0	0	0	
451—500	0	0	0	0	0	
501—550	0	0	0	0	0	
551—600	1	2.0	0	0	0	
Total	51	99.9	223	99.9	105	100.0

* One kan is approximately 3.75 kilograms.

after, table 4 gives the monthly catch, annual total, catch per net-day and so forth. The catch per unit effort in a month has been computed by dividing total with the number of days operated in the corresponding month; that of a year by dividing the annual catch with the annual total of days operated in the corresponding year; the total number of days operated by five seines being used in computing the net-day-catch for the years from 1944 onward. In figure 3 showing fluctuations in the net-day-catch by year, the values plotted for 1925-27 are all higher than 20 kan, whereas most of the intermediate six years 1940-45 indicate the values less than 10 kan, though there are comparatively copious catches as in 1940 and 1943. Particularly in 1942 and 1944 the catch per unit effort is very low or nothing at all as if to warn total futile years that ensued 1946. Now let us see in table 5 and figure 4 frequency percentage of the catch per effort in April and May,

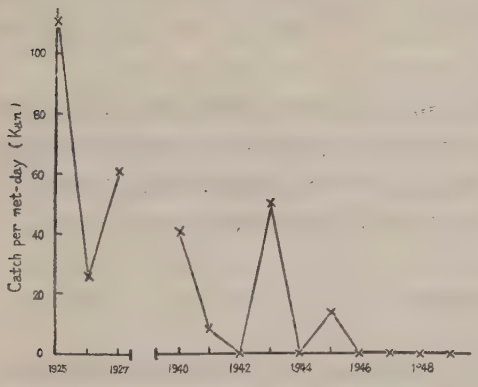

Fig. 3. Fluctuations in the amounts of catch per net-day in "kobira" fishery. One kan is approximately 3.75 kilograms.

$$\frac{\text{frequency of occurrence}}{\text{total of days operated}} \cdot 100,$$

arranged by 50-kan-intervals for subperiods 1925-27 and 1940-45; the table including one more period 1946-49. In the earlier period the frequency in all the class-intervals is higher than that in the intermediate period, while the frequency of futile

fishing days is on the increase one period after another until it reaches 100% in 1946-49 (note of figure 4)

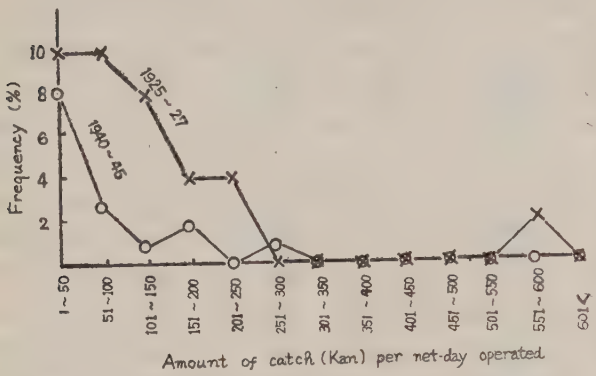

Fig. 4. Frequency of "kobira" catch per net-day by amount-intervals in April and May. Beach seine at Ida-Mura, 1925-27 and 1940-45.

Frequency of no catch 63% for 1925-27
86% for 1940-45
100% for 1946-49

One kan is approximately 3.75 kilograms.

From the above, the catch per effort by year as well as the frequency of catch by weight-class-intervals is supposed to reveal general tendency in immigratory fluctuations of "kobira" during the periods under survey because of the reasons explained at the beginning of this section. In reiterating, the immigration of "kobira" to this region was the most abundant during 1925-27, then showed a very sharp undulation depending on year during 1940-45. The accosting fish, though not so scarce in one year as in another, but anyway were on the decrease as a whole until at last they completely disappeared from the region after 1946. According to oral reports by the fishermen, the amounts of catch were generally greater than those indicated above (Appendix). As yet, except negligible discrepancies in a few years, annual trend of fluctuations in the catch is in a close agreement between the two forms of report, one narrated by them, and the other described here.

In short, the three periods sorted in connection with the cold water off Shiono-misaki and the sardine spawning in Satsu'nan appear to present an interesting correspondence to the periods classifiable in regard to the undulation in the "kobira" fishery off Shichiri-mihama.

Conclusion

When a cold water mass was prevailing off Shiono-misaki prior to 1946, the amount of landings and the duration of season for beach seine fishery off Shichiri-mihama, Mie Prefecture, pursuant to materials A and B, evidently point to a general decline in the amount of young sardine or "kobira" immigrating into the sea off the region, although they were sometimes relatively plentiful and not so nil as at other times. However, from about 1946 onward when the parent sardine are supposed to have

nearly stopped coming and spawning in Satsu'nan, the young completely disappeared from this area, as well. The facts are suggestive of close relationships that must have existed between the "kobira" immigrating into the area, the cold water mass, and vicissitudes of the sardine spawning in Satsu'nan, conforming with the hypotheses advanced as in Introduction.

Before confirming appropriate laws and mechanisms governing these relationships, however, further studies have to be made on the basis of the past and future records of "kobira" fishing, spawning conditions over the pertinent areas, especially distribution and migration of the parent, young and eggs, oceanographic and biological environments. Nevertheless, the facts enumerated above do not seem to contradict, at least in appearance, against the hypotheses proposed in regard to causes of fluctuations in the Japanese sardine stock. Instead, they likely warrant the possibility for furnishing one of circumstantial evidences in support of the hypotheses. Furthermore, if these suppositions are proved fundamentally relevant to the true mechanisms and laws governing the stock, it will be feasible to regard the beach seine situation for "kobira" as one of indices to the undulation in the Japanese sardine stock. Therefore, the fishery aiming at the young sardine off the region may be expected to recover its former prosperity only when the parent fish come back to their old spawning water in Satsu'nan—which is probably one of the prerequisites for the Japanese sardine stock to be restored in their abundance.

Summary

1. The aim of the present study is to investigate fluctuations in immigration of the young sardine, *Sardinops melanosticta* (Temminck et Schlegel) to the waters off Shichiri-mihama on the southeastern coast of Kii Peninsula (fig. 1). The study, it is hoped, may contribute to the knowledge of relationship between a cold water mass once prevailing in an area of Kumano-nada and vicissitudes of spawning activities of the sardine in Satsu'nan Region off the southern end of Kyushu.

2. Nowhere else but in the region under study, the young sardine around 4-8 cm in body length are called "kobira". Because of this unfamiliar name and because of a limited scale of the fishery, no substantial accounts have been given to the fact that the young forms, immigrating there, did support the fishery; left still more obscure were fluctuations in the landings of the one that should have been identified as the young sardine. In addition, most of statistical records kept at the villages were lost in great "tsunamis" the fishermen were suffered from

in 1944 and again in 1946. Therefore, the first approach to the investigation was a direct search for pertinent documents and first-hand information at the villages.

3. In the result, daily records of landings by beach seines at Ida for the periods May 1925 to June 1927, and May 1940 to October 1949, were obtained.

4. Pursuant to these documents, fishing season in the years before 1941 was nearly limited to April and May with the peak taking place around the last ten days of April. After a change occurred in the catch later, the season did not last so long as before and tended to end prior to May (tables 1-3 and fig. 2).

5. Let us have, for the time being, three periods of the years, 1925-27, 1940-45, and 1946-49, in regard to the fishing under study. The catches of the young fish in the intermediate period showed fluctuations from year to year more markedly than in the earlier period, with the amount getting smaller on the whole until there was no catch at all in the last period. The fishermen of the villages state that the total failure of the fishing resulted from that evident change in the situation has been persisting in the region up to the present time (tables 4, 5 and figs. 3, 4).

6. In the earlier period the Kuroshio flowed, as has been known, along its normal course through the waters adjacent to the region, while in the intermediate period a cold water mass was prevailing in Kumanonada. In the last period under study the sardine ceased to immigrate into Satsu'nan for spawning. The fact that those phenomena occurred almost coincidently with depletion in the fishery for young sardine off the region seems to suggest, at least in appearance, relations that likely existed among them.

Mechanisms and laws governing these relations remain to be examined in future. However, if there really existed such relations between the phenomena as assumed here, immigration and production of the young sardine in the vicinity of Kii Peninsula may be expected to come back only when the parent fish return to the former spawning ground in Satsu'nan—which is probably one of the prerequisites for the sardine stock in Japanese waters to be restored in their abundance.

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APPENDIX

Account of Field Interviews on the "Kobira" Beach Seine Fishery Off Shichiri-mihama

In May 1957 when field surveys were undertaken in regard to a work reported in the text, interviews were held with experienced fishermen at the villages visited. Amounts of information given at that time, as they seem to be helpful for understanding a general picture of "kobira" fishery, may be worth being summarized below. Admittedly, numerical values, years and so forth referred to by the fishermen do not necessarily agree with those in the text since their statements have been made without checking these points, one by one, against documents. Inaccurate as some of them may be, these data will be used as they are in compiling the fishermen's oral statements for cross references. The age appearing in parentheses after the name of a person introduced is as of 1957.

Z.N.

Interview at Ida

Mr. Toraichi Uehira (59),
Former Director of the Ida Fishermen's Cooperative:
Mr. En'ichi Nakamichi (67):

Before 1925 the amounts of "kobira" immigrating into the sea had been much greater than those in 1925-35 even though the catch in the later period was fairly thrifty. But the catch started to abate off about 1941-42, and no yield has been made since the end of War (1945). In the thriving years 1933-34, the net-day-catch weighed several thousands of kan (1,000 kan=3.75 metric tons) by a normally large seine, and 3,000 kan by a small one. Occasionally, total landings by six units of seine amounted more than 10,000 kan a day. During the season from the end of March to June, the fish used to come ashore in the evening.

Referring to gear construction, the bag made of spliced net had a length from month to cod-end of about 15 ken (1 ken approx. 1.5 meters in the fishery denomination). The wing, which had been made of cotton net or the like, was substituted by rice straw net from 1921 onward. (Another party of the village remembers the date to be 1917). The length of the wing was about 300 m., and the total length of a seine, 800 m., both on each side.

Interview at Atawa—I

Mr. Kozo Enomoto,
Director of the Atawa Fishermen's Cooperative:
Mr. Keizo Sakaguchi:

Prior to 1908 the yield was not so great as later, despite the fish coming ashore, because of deficient structure of the gear. Since then till 1926 there were copious catches every year, with a greater part of landings being disposed of for farm use. Particularly in 1919 and 1925-26, the fishing thrived with a normal yield ranging from 800 to 1,000 kan a net a day. It was interesting to note that crowds of "kobira" rushed inshore at the beginning of May in 1940 or 41. This lasted for some ten days with the average catch amounting 1,000-2,000 kan per net-day, most of them being used for manure. But no sardine larvae or "aoko" by the local name were seen coming ashore in those days.

The yield in the season around 1943 was as good as 100-150 kan per net-day, then after 1945 not a "kobira" has been caught up to now. The peak of fishing season for "aoko" roughly fell on 17-18th of March, and that for "kobira" sometime in April in those years. Every season before 1908 large sized sardine were fished in plenty, but later the catch was made only on a few days of January and February. In the thriving years of "aoko" and "kobira", larger fish such as mackerel, jack mackerel and hairtail were caught in a great amount as they used to throng together inshore in pursuit of the young sardine. But after "kobira" disappeared from the area, they ceased to come in, either.

From about 1918, rice straw net replaced cotton for the wing of the seine.

Interview at Atawa—II

Mr. Fumihiko Shibaai (49):

Since my boy's day till about 1938 quantities of "kobira" used to be landed; then in 1939, the fishing was a complete failure. A fairly good catch we had in 1945 did not last any longer, and no trace of the fish has been seen till now. In the prosperous days, daily landings of "kobira" amounted to 1,000 kan on the average per net or 1,500 kan at best. The total catch of the season covering two months ranged usually from 10,000 to 15,000 kan. One-third of them were processed into a dried form for seasoning, the rest disposed of for manure. The season extended from March to the end of April with the middle of April as the peak when the annual festival for the village shrine was to be held. The sardine larvae known by the name "akahara" came inshore around February; then in March they were found mixed with "kaeri" or juvenile

measuring some 6 cm. The fish used to approach ashore in the evening, forming a black throng.

As for the gear, both the bag and the wing had been made of cotton or hemp through the later half of 1800's until 1915 or so, then rice stalk net was introduced for the wing, and about ten years later, spliced net came in use for the bag. The side length of the wing had been 300 ken until recently when it was extended over 500 ken for the specific purpose of catching the anchovy. In the village there are five sites for the beach seining operation; five units out of six seines are using them alternatively from one site to another, one unit always waiting for its turn to operate.

Interview at Kinomoto

Mr. Iwakichi Hamamoto (63):

Mr. Kan'ichi Hamamoto (37), his son:

The fishing for "kobira" was continuously practised from the later part of 1800's till about 1942. Although an exact amount of catch is not available, a better catch used to occur about once a year with every net landing some 500 baskets of the fish, estimated at 5,000 kan a day. With a normal day's catch amounting some 1,000 kan a net, an estimated yield of "kobira" was 15,000-20,000 kan per net-season, and 30,000-50,000 kan in a thrifty year, with the value per 10 kan ranging from 35 to 50 sen (then 100 sen approx. 50 U.S. cents) depending on market. Sometime around 1940 the net-day yield was as good as 1,000-1,500 kan. When the landings were that much, part of them was sold for manure. But since then no yield of the young fish has been made up to now.

In the season, March and April, the fishermen set out for operation in the evening when they took a sight of incoming schools of "kobira".

The measurement of the bag was 25 ken in length; the wing, 200 ken on each side; total side length, 500 ken. The bag had been made of cotton net, 9 plies, with 25 stretch knots per unit length of *ca.* 15 cm. or a mesh aperture *ca.* 1.5 cm. before it was replaced by spliced net having 6 and 4 plies for warp and woof, and 105 meshes per unit length of 34 cm.

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THE VARIATION OF HYDROGRAPHIC CONDITION IN URADO BAY

By Hiroshi Yamamoto
(Chemistry Institute, Faculty of Education, Kochi University)

Introduction

It goes without saying that the chemical properties of inlet water are goverened by the various conditions of outer ocean, and besides in the inlet where land water flows in, they are surprisingly altered by the configuration of a land and the nature of land water.

The author has studied in order to make clear and explain the kind of chemical elements and the aspects of circulation of these elements as the factors, which control the productivity in the inlets of our country, and I have come to the conclusions as follows:

Among the various features of the inlets, especially in such an inlet as Urado Bay, where sea water is diluted by land water, notable discontinuities have been formed at an average depth of 1.5 meters, between the surface layer diluted by the land water and bottom layer influenced by ocean water.

So we have pleasure to report about the seasonal changes of water temperature and chlorinity in Urado Bay where the features of land water appears, according to the data collected between June and December in 1955.

It may be difficult to judge exactly the hydrographic condition from the seasonal changes of water temperature and chlorinity alone, but they are thought to give enough information to understand the outline of seasonal changes of the hydrographic conditions in the inlet of Urado Bay.

Chapter 1

Method of Observation

We have observed, as shown in Fig. 1, the surface and 3m. layer at the fifteen stations in Urado Bay, and care was taken that every observation could be carried out at approximately the same time.

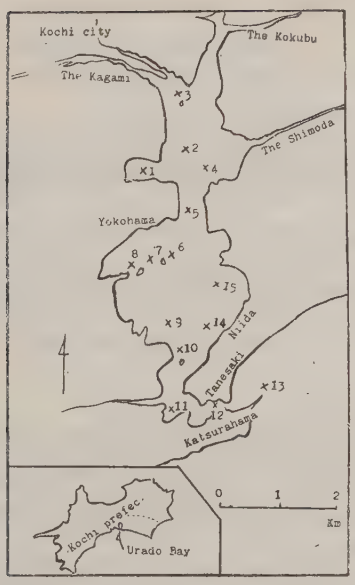

Fig. 1. Observational stations in Urado Bay.

With regard to the measurement of chlorinity, we used the Mothr's method, adding 10% solution of potassium chromate as an indicator.

The results of the observation at different points were such that the fifteen stations classed themselves into three groups.

Group I is composed of stations 1-5, Group II of stations 6-9, 14 and 15, and Group III of stations 10-13.

In Group I the land water directly touches sea water, and the degree of their mixing is not advanced yet.

As a rule, this group is shallow in depth and is situated to the north of the narrow part in the middle of Urado Bay. See Table 1)

As to Group II, water there is regarded as peculiar to this inlet.

Last of all, Group II belongs to the area where inlet water and ocean water get in contact to the greatest degree.

Results and Discussion

A) Water temperature

Fig. 2 is an isopleth representation of the seasonal changes in water temperature.

The abscissa indicates the representative stations of each group and, although these stations are in fact not at equal intervals, they are so represented for the sake of convenience.

At suface layers the lowest tempareture is seen in January and February, while the highest one appears from the end of August to the beginning of September.

It was at stations 3 and 15 that the lowest and the highest temperature was registered. This seems to be due to the inflow of land water and the depth of water at these stations.

Fig. 3 shows the seasonal change of water temperature at stations 3, 15 and 13 as representing Group I, II, and III respectively.

The temperature of surface layers tends to be much wider in its range than that of bottom layers, but the difference of temperature in each layer is small in the period from December to May.

Table 1. Chlorinity & temperature of each observational stations.

St.	June				July				Aug.				Sept.			
	Temp.(C)		Cl ‰		Temp.(C)		Cl ‰		Temp.(C)		Cl ‰		Temp.(C)		Cl ‰	
	0m	3m	0m	3m	0m	3m	0m	3m	0m	3m	0m	3m	0m	3m	0m	3m
1	24.70	22.70	4.13	16.72	27.15	26.30	3.36	13.41	31.12	29.50	6.80	15.72	27.70	28.91	10.50	16.12
2	23.05	22.50	4.04	12.85	24.8	25.70	2.46	13.99	29.30	29.10	4.53	15.35	26.70	28.3	9.36	14.90
3	22.34	23.25	4.51	8.72	23.10	24.20	3.62	15.10	27.91	29.20	6.02	15.91	26.10	28.05	5.41	15.15
4	23.79	22.95	4.55	14.20	25.30	24.63	4.36	14.61	28.67	29.20	7.90	16.50	26.30	28.05	10.70	16.62
5	23.13	23.09	3.71	16.91	26.00	25.82	5.00	16.90	29.72	29.21	6.72	17.40	27.20	28.00	12.10	16.85
6	23.73	22.83	6.41	12.50	25.50	26.20	5.42	15.50	80.71	29.30	7.52	16.43	27.30	28.00	12.63	17.21
7	23.41	22.70	5.72	14.83	27.31	26.50	6.41	13.72	30.30	29.52	9.21	16.24	27.00	28.21	12.73	18.50
8	24.01	23.01	4.61	14.15	27.30	26.73	5.43	14.91	29.81	29.40	8.30	16.05	27.30	28.30	12.30	16.14
9	23.29	22.54	5.25	17.10	27.24	26.00	5.10	15.61	30.62	29.31	8.25	15.82	27.48	28.29	11.81	16.52
10	23.62	22.75	8.63	16.12	26.80	26.35	5.72	17.04	30.40	28.95	7.60	16.61	27.43	27.93	8.40	17.50
11	23.42	23.04	8.62	16.12	27.00	26.05	6.11	16.02	30.21	29.00	10.70	17.04	27.25	28.00	12.91	16.95
12	23.31	23.00	12.68	18.00	27.00	26.38	12.95	17.00	32.20	29.04	11.10	17.12	27.40	28.10	13.40	17.90
13	23.25	22.56	16.20	18.21	26.65	26.16	9.93	17.14	31.00	29.10	12.50	17.29	27.71	30.00	15.32	17.81
14	25.00	23.50	5.29	12.61	26.90	26.40	5.76	15.21	30.52	30.00	8.67	13.21	27.38	28.05	11.95	13.41
15	24.62	23.84	4.32	12.14	27.43	26.10	4.54	13.30	30.61	30.00	8.65	14.30	35.01	27.93	11.91	14.32

St.	Oct.				Nov.				Dec.			
	Temp.(C)		Cl ‰		Temp.(C)		Cl ‰		Temp.(C)		Cl ‰	
	0m	3m	0m	3m	0m	3m	0m	3m	0m	3m	0m	3m
1	22.20	23.12	12.60	16.31	19.00	21.90	10.65	16.40	17.91	18.70	15.43	17.10
2	22.70	23.45	11.50	15.03	17.12	21.20	11.84	16.55	15.83	18.51	13.50	16.66
3	21.10	24.00	9.45	14.10	18.80	21.10	8.50	15.20	14.32	17.70	11.30	15.00
4	21.40	23.95	11.00	16.75	18.95	21.20	10.05	16.34	15.20	17.30	13.12	16.80
5	21.99	23.80	11.10	17.19	19.32	21.90	10.62	15.97	16.31	18.82	13.64	16.70
6	21.20	23.81	11.31	16.82	22.12	21.60	9.80	14.84	26.60	28.93	15.51	17.3
7	21.90	24.90	12.82	16.13	19.51	21.60	11.90	15.42	16.40	19.13	15.50	17.41
8	22.51	23.60	13.34	15.32	19.40	21.71	12.51	16.25	16.70	18.10	13.15	17.13
9	22.22	23.93	11.73	17.36	19.62	21.63	11.51	16.13	16.63	18.92	15.63	17.14
10	22.21	24.10	13.12	17.30	20.60	22.10	11.30	16.82	17.12	19.31	16.12	17.70
11	22.50	23.32	13.90	17.40	20.60	22.05	12.60	16.71	16.05	18.72	15.40	17.30
12	23.20	23.90	14.72	17.20	21.41	22.31	13.32	17.14	18.00	19.50	17.23	17.92
13	23.05	23.30	16.20	18.30	22.13	22.30	16.09	18.05	19.23	19.10	17.36	18.44
14	22.40	23.35	10.72	13.71	20.30	21.15	12.20	15.45	17.05	17.25	15.41	16.60
15	23.50	23.90	13.20	15.21	20.25	21.60	12.45	15.93	16.60	18.05	15.81	16.80

The temperature of each layer is found to fall lowest at nearly same time.

The time of each layer to go down lowest keeps abreast with each other.

The table 2 shows the "range" of the temperature of each station,

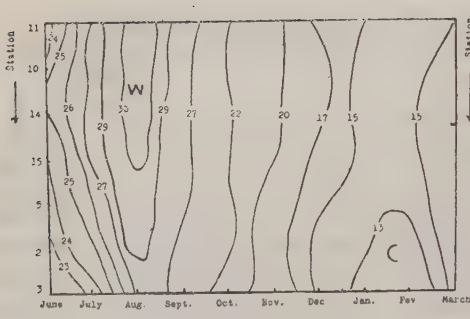

Fig. 2—a. Isopleth representation of the seasonal changes in water temperature at surface layer.

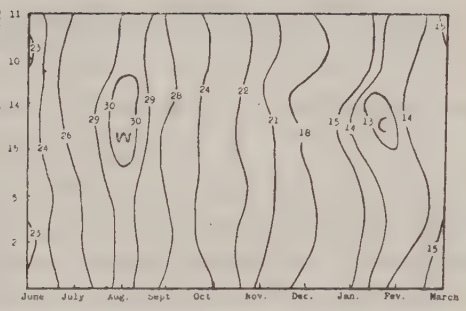

Fig. 2—b. Isopleth representation of seasonal changes in water temperature at 3 m.-layer.

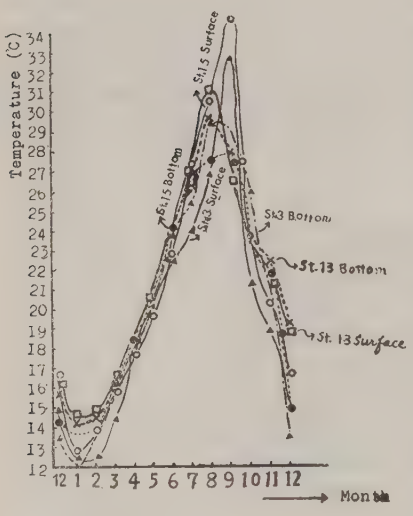

Fig. 3. Seasonal variation of water temperature at St. 3, 13 and 15.

through which we are able to find that the range gradually decreases in proportion as the depth of water becomes deep, and that there is no peculiar phenomenon about each station in the point of the range of the surface layers, but that the range of temperature of all stations, that belongs to the Group I, is a little great, as compared with the other stations.

So far as bottom layers are concerned, the great range is recognized among the stations of Group I and II, while we find the range to be almost identical at the stations of Group III.

This is considered to be much related to the flowering movement of sea water by the tide.

Thus a noticeable feature is that the range of temperature is very great in such an inlet, taking on the features of land water, as Urado Bay, and that annual change is comparatively regular.

We cannot find any irregular circulation through every station.

B) Chlorinity

It is generally observed that chlorinity tends to increase in winter and to decrease in summer.

varies according to season, and there is a great difference between the

The concentration of chlorinity in surface layers extraordinarily

Table 2. Range of temperature between surface layer and the bottom.

St.	surface	bottom	average depth
1	20.0	15.4	4.5
2	17.0	15.1	3.6
3	20.3	17.4	3.7
4	18.6	14.9	4.9
5	18.1	14.8	6.6
6	17.7	15.3	4.6
7	17.0	14.5	3.2
8	17.2	16.0	2.6
9	17.3	15.1	4.5
10	17.0	14.3	21.9
11	16.8	14.8	7.0
12	17.4	14.3	7.1
13	16.5	14.4	6.1
14	17.9	16.2	1.9
15	21.7	14.5	2.2

chlorinity of surface layer and that of bottom layers.

This denotes that Urado Bay is liable to be influenced by the land water and governed by the seasonal change of rainfall and sunshine.

As compared with the remarkable change of surface layers, the change in the bottom layers is exceedingly small.

This is probably due to the fact that the sea water, which has its origin in the Kuroshio, flows into the inlet at the bottom layers with almost the same chlorinity through the seasons.

From June to September all stations except every station of Group III indicate also nearly the same difference and the value 5-7 ‰ is registered.

From October this tendency is confused and the difference decreases, both surface and bottom layers being approximate each other.

Namely, it is supposed that this is the phenomena of the turning point of season and the mixing of the surface and bottom layers due to the inversion of water temperature.

If we have made a close examination of these relations with regard to every group above-mentioned, the tendency of Group I is that there is a great change at each layer.

This makes us known the chlorinity of the inner part of the bay is entirely influenced by the flowering of land water and the tide, and it is variable.

The bottom layers are liable to be easily influenced by the variation of surface layers, on account of shallow depth (3-4m).

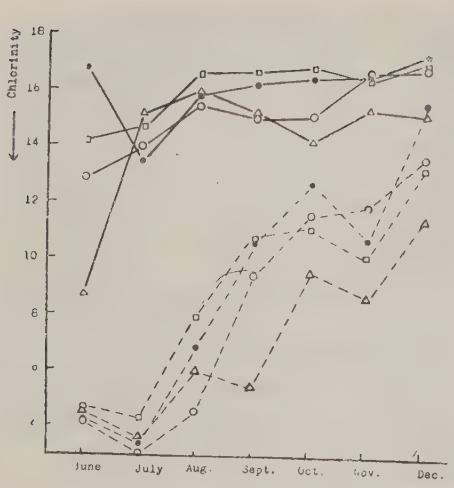

Fig. 4—a. Seasonal variation of chlorinity at each stations in Group 1
In this figure, continued line; 3 m layer, dotted line; surface layer, ——st. 1, —st. 2, —st. 3, —st. 4.

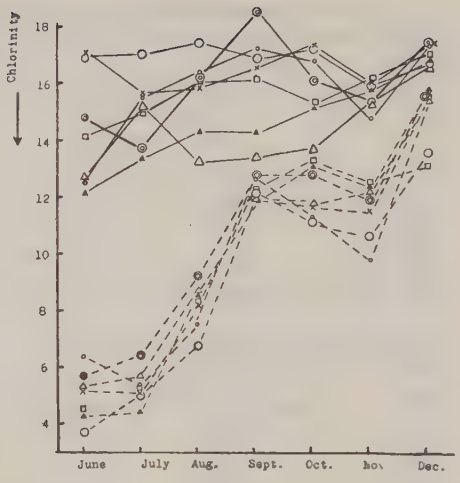

Fig. 4—b Seasonal variation of chlorinity at each stations in Group 2 surface layer, —st. 6, —st. 7, —st. 8, —st. 9, —st. 14, —st. 15, —st. 5.

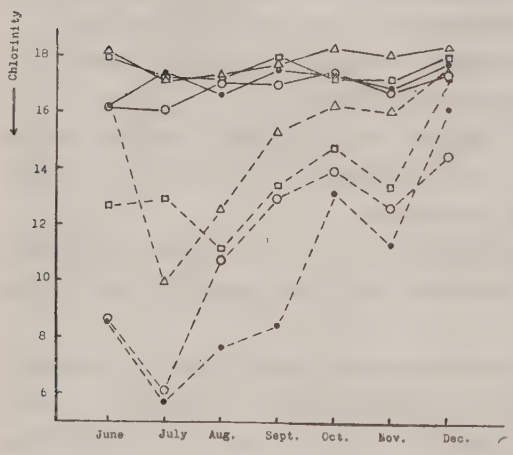

Fig. 4—c. Seasonal variation of Chlorinity at each stations in Group 3.
In this figure, continued line; 3 m layer, Dotted line; surface layer, △○—st. 10, —st. 11, □—st. 12.

It is sure that the tendency of this group is generally similar to others.

But, in this group, the differences among each station are very noticeable.

As to Group II, what is different from Group I is that at the surface there is hardly recognized any difference among each station, but at the bottom much difference can be seen.

As a rule, a little variation can be observed, that is, a peak is seen between September and October, and in November the tendency of a slight diminution can also be seen. This diminution, however, ceases at 17‰ and a recovery soon appears.

Thus every station has a common tendency, which spreads over the all parts of this bay, as we cannot catch the inflow of more condenced water when it suffers from the influence of land water in this area.

Judging from the structure of the continuous layers which we have already observed, the velocity and direction of inflow of surface layers are guessed to be difficult from these of bottom layers, so that the difference of chlorinity of bottom layers caused by the tide is characteristic of this area.

On the other hand, there is no great difference at bottom layers in Group III, because this group is inclined to be governed by a mass of water of high density.

The features of Group III are that the transformation from the so-called inlet water into the ocean water is well indicated.

The station 13 shows a tendency to take on the nature of outer ocean, as this station is directly influenced by the ocean water.

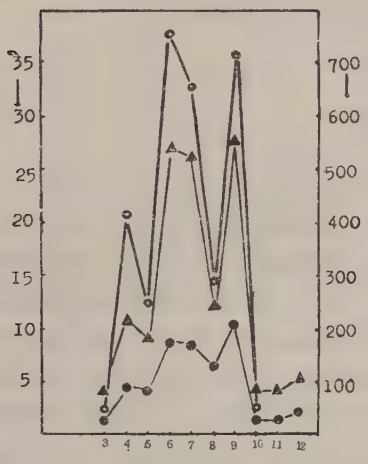

Fig. 5. Seasonal relation between vertical inclination and volume of reine fall.

Except the lower density of sea water, in July and August, caused by the rainfall, the difference between surface and bottom layers is the smallest, 2-3‰.

Referred to the difference of chlorinity of each station, the higher difference is gradually adjacent to the smallest one of the station 13.

Now we have explained that the dilution of the inlet water by the rainfall and land water varies the hydrographic condition and we researched the vertical inclination of chlorinity at each station, of which the highest point we compared with the quantity of the rainfall, which was measured at the Kochi Meteorological Station.

In consequence of this, we find the interrelation as Fig. 5 shows.

Conclusion

From the change of water temperature and chlorinity, we have mentioned about the seasonal variation of the hydrographic condition of Urado Bay.

In such an inlet diluted with land water, the ratio of ingredients of chemical elements much differences from the ratio of off sea water and it is very important how much change inlet water undergoes.

This is to be made clear through the variation of chlorinity, and the quantity of saturation of dissolved oxygen is more considerable at surface than at bottom layers.

Though we have observed the vicissitude of silicate-Si and phosphate-

P, this time we want to report mainly about the variation of the hydrographic condition through the change of chlorinity, and we will reserve a report of other chemical elements for another opportunity.

I should like to thank Prof. M. Ishibashi of Kyoto University for suggestion a number of the methods of this observation, and Mr. Y. Imai of Kochi University for kindly technical assistance.

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STUDIES ON THE UTILIZATION OF THE SHALLOW-WATER DEPOSITS (Continued)

On the Copper Content of the Shallow-water Deposits at the Seacoasts of the Kii Peninsula and the Other Districts

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Introduction

Previously, the authors reported on the contents of common elements and rare or trace elements such as radium, vanadium, chromium and nickel in about 140 shallow-water deposits collected at the sea-coasts of Korea and Honshū Island[1]. This time, the authors collected 27 samples of deposit at the sea-coasts of the Kii Peninsula and determined their copper content. All the samples cited above were also analysed for copper. Furthermore, in order to investigate the relation between the copper content and geology, the authors analysed deposits from various small islands having relatively simple geological structure.

Experimental Procedure and Results

Determination of copper was carried out mainly by the dithizone method of E.B. Sandell[2].

(1) On the Copper Content of the Shallow-water Deposits.

The analytical results obtained are shown in Table 1 for the Kii samples and in Table 2 for the other Honshū samples and the Korean samples. The figures are shown on the sea-salt-free and dry basis.

From Table 1, we shall consider the copper content of the deposits from Wakayama Prefecture. Samples 301A~E were collected in the neighbourhood of Kainan City where crystalline schists predominate. The copper content is low in Samples 301A, B from Nagusahama, and relatively high in Samples 301C~E from Kuroe Bay, especially in Sample 301D which was collected at the mouth of the Hikata River.

The following samples were collected in Tanabe Bay, where Tertiary

Table 1. Copper content of the shallow-water deposits from the Kii Peninsula.

Sample No.	Locality	Type of deposits	Cu content 10^{-4}%
301_A	Kemi, Wakayama-shi, Wakayama-ken	brown sand	2
301_B	Kemi, Wakayama-shi, Wakayama-ken	grayish brown sand	2
301_C	Kotonoura, Kainan-shi, Wakayama-ken	grayish sand	14
301_D	Hikata, Kainan-shi, Wakayama-ken	grayish sandy mud	38
301_E	Fujishiro, Kainan-shi, Wakayama-ken	grayish sandy mud	15
78	Enokoma, Yura-machi, Hidaka-gun, Wakayama-ken	light brown sand	5
77	Minabe-machi, Hidaka-gen, Wakayama-ken	brown sand	12
76	Kitahara, Shinjō-mura, Nishimuro-gun, Wakayama-ken	light brown sandy mud	9
309_A	Uchinoura, Shinjō-machi, Tanabe-shi, Wakayama-ken	brown mud	8
309_B	Uchinoura, Shinjō-machi, Tanabe-shi, Wakayama-ken	brown sandy mud	trace
309_C	Uchinoura, Shinjō-machi, Tanabe-shi, Wakayama-ken	brown sandy mud	3
309_D	Torinosu, Shinjō-machi, Tanabe-shi, Wakayama-ken	brown sandy mud	2
309_E	Uchinoura, Shinjo-machi, Tanabe-shi, Wakayama-ken	dark brown mud	19
75	Hosono, Katata, Nishitonda-mura, Nishimuro-gun, Wakayama-ken	light brown sandy mud	11
307_A	Shirahama-machi, Nishimuro-gun, Wakayama-ken	brown sandy mud	4
307_B	Shirahama-machi, Nishimuro-gun, Wakayama-ken	brown sandy mud	7
307_C	Shirahama-machi, Nishimuro-gun, Wakayama-ken	grayish brown sandy mud	4
307_D	Shirahama-machi, Nishimuro-gun, Wakayama-ken	graysh brown sandy mud	4
307_E	Shirahama-machi, Nishimuro-gun, Wakayama-ken	brown sany mud	7
74	Miwasaki-machi, Shingū-shi, Wakayama-ken	blakish brown sand	18
81	Nagashima-machi, Kitamuro-gun, Mie-ken	blackish brown sand	12

305_A	Nishiki-machi, Kitamuro-gun, Mie-ken	blackish brown sand	22
305_B	Nishiki-machi, Kitamuro-gun, Mie-ken	glayish brown sand	108
305_C	Nishiki-machi, Kitamuro-gun, Mie-ken	brown sand	11
305_D	Nishiki-machi, Kitamuro-gun, Mie-ken	brown sand	10
306_A	Nieura, Nanto-machi, Watarai-gun, Mie-ken	grayish white sandy mud	10
306_B	Nieura, Nanto-machi, Watarai-gun, Mie-ken	blackish brown sand	6
306_C	Nieura, Nanto-machi, Watarai-gun, Mie-ken	blackish gray sand	11
80	Funagoshi-mura, Shima-gun, Mie-ken	grayish white sandy mud	24
310_A	Kariya, Momotori-machi, Taba-shi, Mie-ken	grayish green sandy mud	73
310_B	Kariya, Mototori-machi, Toba-shi, Mie-ken	greenish brown sandy mud	117
310_C	Kariya, Momotori-machi, Toba-shi, Mie-ken	greenish mud	114
310_D	Kariya, Mototori-machi, Toba-shi, Mie-ken	grayish brown sandy mud	78
310_E	Kariya, Momotori-machi, Toba-shi, Mie-ken	brown sandy mud	26
79	Ōyodo, Ōyodo-machi, Take-gun, Mie-ken	light grayish brown sand	1

Table 2. Copper content of the shallow-water deposits from Honshū (excluding Kii) and Korea.

Sample No.	Locality	Type of deposis	Cu content 10^{-4}%
1	Ataka-machi, Komatsu-shi, Ishikawa-ken	light brown sand	3
2	Mukōzawagasaki, Uchinada-mura, Kahoku-gun, Ishikawa-ken	brown sand	7
3	Takahama, Takahama-machi, Hukui-gun, Ishikawa-ken	light brown sand	4
4	Ōkawa, Machino-machi, Fugeshi-gun, Ishikawa-ken	blackish sand	21
5	Fujinami, Sannami-mura, Fugeshi-gun, Ishikawa-ken	light brown sand	10
6	Mattō, Nanao-shi, Ishikawa-ken	light grayish brown sand	11
7	Kubo, Kubo-mura, Himi-gun, Toyama-ken	light brown sand	5
8	Ebie, Ebie-mura, Imizu-gun, Toyama-ken	light grayish brown sand	4
9	Shimomuraki-machi, Uozu-machi, Shimoniikawa-gun, Toyama-ken	light yellowish sand	5
10	Ikuji-machi, Shimoniikawa-gun, Toyama-ken	small gravel	n. d.
11	Shimoarahama, Yachiho-mura, Nakakubiki-gun, Niigata-ken	grayish white sand	12
12	Kujiranami, Kashiwazaki-shi, Niigata-ken	blackish brown sand	9
13	Amaze, Izumozaki-machi, Santō-gun, Niigata-ken	brown sand	8
14	Kawakami, Ikarashihama, Uchino-machi, Nishikambara-gun, Niigata-ken	grayish white sand	16
15	Muramatsuhama, Matsuzuka-mura, Kitakambara-gnn, Niigata-ken	grayish white sand	8
16	Aburato, Kamo-machi, Nishitagawa-gun, Yamagata-ken	grayish sand	17
17	Miyaumi, Nishiarase-mura, Akuumi-gun, Yamagata-ken	grayish white sand	4
18	Yoshigo, Tahara-machi, Atsumi-gun, Aichi-ken	grayish green fine mud	23
19	Ura, Tahara-machi, Atsumi-gun, Aichi-ken	grayish green sandy mud	19
20	Namiirie, Oitsu-mura, Atsumi-gun, Aichi-ken	grayish green sandy mud	11

21	Nakane, Terazu-machi, Hazu-gun, Aichi-ken	grayish green sandy mud	4
22	Yashihama, Takahama-machi, Hekikai-gun, Aichi-ken	grayish green fine mud	28
23	Ishikiri, Kamezaki, Handa-shi, Aichi-ken	grayish green sandy mud	n. d.
24	Nawa, Ueno-machi, Chita-gun, Aichi-ken	grayish green mud	9
25	Sankaku, Shimonoishiki-machi, Nakagawa-ku, Nagoya-shi, Aichi-ken	grayish green fine mud	22
26	Shingai-machi, Fukuyama-shi, Hiroshima-ken	grayish green fine mud	28
27	Minomi-machi, Numakuma-gun, Hiroshima-ken	grayish green fine mud	28
28	Yoshiwa-machi, Onomichi-shi, Hiroshima-ken	grayish green mud	16
29	Nouji, Saizaki-machi, Toyota-gun, Hiroshima-ken	yellowish white sand	6
30	Miyatoko, Tadanoumi-machi, Toyota-gun, Hiroshima-ken	light brown sand	2
31	Kitazaki, Takehara-machi, Kamo-gun, Hiroshima-ken	grayish green fine mud	240
32	Kirasaki, Shimono-mura, Kamo-gun, Hiroshima-ken	grayish green mud	25
33	Mitsu, Akitsu-machi, Kamo-gun, Hiroshima-ken	light grayish brayish brown sand	2
34	Tsukimigahama, Itsukaichi, Itsukaichi-machi, Saeki-gun, Hiroshima-ken	light brown sand	6
35	Karasumori, Uchimichikawa, Michikawa-mura, Yuri-gun, Akita-ken	grayish white sand	8
36	Shimodeto, Tennō-mura, Minamiakita-gun, Akita-ken	brown sand	11
37	Minamihirasawa, Funagawaminato-machi, Minamiakita-gun, Akita-ken	grayish white sand	8
38	Miyasawa, Katanishi-mura, Minamiakita-gun, Akita-ken	brown sand	12
39	Kohama, Kurosaki, Iwasaki-mura, Nishitsugaru-gun, Aomori-ken	grayish white sand	trace
40	Isouchi, Rokumaibashi, Ushirogata-mura, Higashitsugaru-gun, Aomori-ken	blackish sand	6

41	Asadokoro, Kominato-machi, Higashitsugaru-gun, Aomori-ken	grayish sand	18
42	Uwano, Ōhata, Ōhata-machi, Shimokita-gun, Aomori-ken	brown sand	5
43	Tomari, Rokukasho-mura, Kamikita-gun, Aomori-ken	blackish brown sand	5
44	Hitokawame, Momoishi-machi, Kamikita-gun, Aomori-ken	blackish sand	9
45	Tamakawa, Noda-mura, Kunohe-gun, Iwate-ken	grayish white sand	16
46	Fujiwara, Miyako-shi, Iwate-ken	blackish sand	16
47	Tsugaruishi-mura, Shimohei-gun, Iwate-ken	grayish white sand	9
48	Orikasa-mura, Shimohei-gun, Iwate-ken	dark grayish sandy mud	25
49	Akasawa, Ōfunato-machi, Kesen-gun, Iwate-ken	blackish sand	13
50	Okiura, Higashikatakami, Katakami-machi, Wake-gun, Okayama-ken	dark grayish green fine mud	67
82	Awarigō, Nagahama-mura, Oku-gun, Okayama-ken	grayish green sandy mud	120
51	Nishitakasaki, Nadasaki-mura, Kojima-gun, Okayama-ken	grayish green fine mud	28
52	Nishitakasaki, Nadasaki-mura, Kojima-gun, Okayama-ken	grayisn green fine mud	11
53	Cōsaki, Hachihama-machi, Kojima-gun, Okayama-ken	grayish green fine mud	20
54	Hachihama-machi, Kojima-gun, Okayama-ken	grayish green mud	10
55	Yorishima-machi, Asaguchi-gun, Okayama-ken	grayish green mud	15
56	Yōsuna, Kanaura-machi, Oda-gun, Okayama-ken	grayish green mnd	15
57	Yanai-machi, Kuga-gun, Yamaguchi-ken	grayish green mud	28
58	Shinzaki, Higashitoyoi, Kudamatsu-shi, Yamaguchi-ken	grayish white sand	9
59	Nihomasu, Nakanoseki-machi, Hōfu-shi, Yamaguchi-ken	grayish grenn mud	14
60	Kiwaura, Higashikiwa-mura, Yoshiki-gun, Yamaguchi-ken	yellowish white sand	4
61	Matsuoda, Shimonoseki-shi, Yamaguchi-ken	yellowish white sand	7

62	Ōhibi, Senzaki-machi, Ōtsu-gun, Yamaguchi-ken	light brownish gray sand	12
63	Ōku, Nago-machi, Abu-gun, Yamaguchi-ken	grayish sand	3
64	Asari-mura, Naka-gun, Shimane-ken	yellowish white sand	9
65	Yasugi, Yasugi-machi, Nogi-gun, Shimane-ken	brown sand	4
66	Yoshizu, Sakitsu-mura, Saihaku-gun, Tottori-ken	grayish sand	12
67	Ōshinozu-mura, Saihaku-gun, Tottori-ken	yellowish white sand	20
68	Yodoe, Yodoe-machi, Saihaku-gun, Tottori-ken	grayish sand	16
69	Ajiro-mura, Iwami-gun, Tottori-ken	light brown sand	172
70	Ōkura-machi, Akashi-shi, Hyogo-ken	yellowish white sand	12
71	Shinzaike, Aboshi-ku, Himeji-shi, Hyōgo-ken	grayish brown sand	11
72	Naba-machi, Aioi-shi, Hyōgo-ken	grayish green sand	26
73	Naba-machi, Aioi-shi, Hyōgo-ken	grayish green mud	32
83	Suna, Hasunuma-mura, Sanbu-gun, Chiba-ken	light brown sand	23
84	Hama-machi, Anesaki, Anesaki-machi, Ichihara-gun, Chiba-ken	blackish gray sand	2
85	Hon-machi, Funabashi-shi, Chiba-ken	light blakish brown sand	10
86	Kanazawa-machi, Isogo-ku, Yokohama-shi, Kanagawa-ken	grayish sand	8
87	Ōiso, Ōiso-machi, Naka-gun, Kanagawa-ken	blackish sand	71
88	Sakawa, Sakawa-machi, Ashigara-noshimo-gun, Kanagawa-ken	blackish sand	45
89	Usami-mura, Tagata-gun, Shizuoka-ken	blackish brown sand	15
90	Tago, Tagonoura-mura, Fuji-gun, Shizuoka-ken	blackish gray sand	21
91	Chihama, Chihama-mura, Ogasa-gun, Shizuoka-ken	light blackish gray sand	7
92	Hamana, Arai-machi, Hamana-gun, Shizuoka-ken	light blackish gray sand	6
111	Namiita, Shishiori-mura, Motoyoshi-gun, Miyagi-ken	grayish sandy mud	41

93	Namiita, Shishiori-gun, Miyagi-ken	grayish mud	78
94	Shizukawa-machi, Motoyoshi-gun, Miyagi-ken	grayish white sand	6
95	Ōmagari, Yamoto-machi, Monou-gun, Miyagi-ken	light brown sand	9
96	Nakahama, Sakamoto, Sakamoto-mura, Watari-gun, Miyagi-ken	light yellowish gray sand	3
97	Shin-machi, Ukedo, Uedo-mura, Futaba-gun, Fukushima-ken	light brownish gray sand	2
98	Naka-machi, Yotsukura-machi, Iwaki-gun, Fukushima-ken	light yellowish gray sand	4
99	Kawajiri, Toyoura-machi, Taga-gun, Ibaraki-ken	light brownish gray sand	7
100	Akashi, Namino-mura, Kashima-gun, Ibaraki-ken	light brownish gray sand	5
101	Yoshimi, Tajiri-mura, Sennan-gun, Ōsaka-fu	yellowish brown sand	3
110	Kamiya-machi, Kishiwada-shi, Ōsaka-fu	yellowish brown sand	10
102	Shiomi-machi, Izumiōtsu-shi, Ōsaka-fu	light yellowish brown sand	18
103	Hamazume-mura, Takeno-gun, Kyōto-fu	light brown sand	11
104	Iwagahana, Yōrō-mura, Yoza-gun, Kyōto-fu	light brown sand	6
109	Shimasaki, Miyazu-machi, Yoza-gun, Kyōto-fu	yellowish brown sand	14
105	Higashikanzaki, Kanzaki-mura, Kasa-gun, Kyōto-fu	light brownish gray sand	12
106	Wakamiya, Takahama-machi, Oi-gun, Fukui-ken	greenish black sand	8
107	Shirahige, Obama-machi, Onyū-gun, Fukui-ken	grayish brown sand	15
108	Ishishinbo, Natsume-mura, Sakai-gun, Fukui-ken	brown sand	1
K 1	Puna, Yongchon-kun, Pyongan-pukto	dark brown mud	n. d.
K 2	Osong-tong, Taesan-myon, Sonchon-kun, Pyogan-pukto	dark brown mud	3
K 3	Hmpal-ri, Hanchon-myon, Pyong-won-kun, Pyongan-namdo	dark brown mud	10
K 4	Okangki-ri, Chinnampopu, Pyonan-namdo	dark brown mud	27
K 5	Yonghoto-ri, Tongnam-myon, On-jin-kun, Hwanghae-do	dark brown mud	7

K 6	Chinjong-ri, Sonwon-myon, Kanghwa-kun, Kyonggi-do	dark brown mud	7
K 7	Tongjoung-ri, Soukmun-myon, Tangjin-kun, Chungchong-namdo	dark brown mud	21
K 8	Sopinchon, Kunsanpu, Cholla-pukto	dark brown mud	35
K 9	Namchang-ri, Pukpyong-myon, Haenam-kun, Cholla-namdo	dark brown mud	12
K 10	Mayang-ri, Taeku-myon, Kangjin-kun, Cholla-namdo	dark brown mud	12
K 11	Haean, Kuhangshine, Yosu-ub, Yosu-kun, Cholla-namdo	dark brown mud	64
K 12_1	Royang-ri, Kumnan-myon, Hadong-kun, Kyongsang-namdo	dark brown sandy mud	19
K 12_2	Royang-ri, Kumnan-myon, Hadong-kun, Kyongsang-namdo	dark brown sandy mud	11
K 13	Sonjin-ri, Yongkyo-myon, Sachon-kun, Kyongsang-namdo	dark brown sandy mud	10
K 14	Tupu-ri, Samsan-myon, Kosong-kun, Kyongsang-namdo	brown mud	16
K 15	Shinjon-ri, Sanyang-myon, Tongyong-kun, Kyongsang-namdo	dark brown sandy mud	13
K 16	Kyonghwa-tong, Chinhae-ub, Changwon-kun, Kyongsang-namdo	brown mud	47
K 17	Chedok-ri, Ungchon-myon, Changwon-kun, Kyongsang-namdo	dark brown mud	16
K 18	Bangou-ri, Tong-myon, Ulsan-kun, Kyongsang-namdo	yellow clay	19
K 19_1	Pohang-tong, Pohang-ub, Yongil-kun, Kyongsang-pukto	dark brown mud	25
K 19_2	Pohang-tong, Pohang-ub, Yongil-kun, Kyongsang-pukto	light yellowish brown sand	1
K 20	Imwon-ri, Wondok-myon, Samchok-kun, Kangwon-do	light yellowish brown sand	7
K 21	Chumun-ri, Chumunjin-myon, Kangnung-kun, Kangwon-do	yellowish white sand	4
K 22	Haean-tong, Wonsanpu, Hamgyong-namdo	light brown sand	3
K 23	Hengchon, Songjin-ub, Songjin-kun, Hamgyong-pukto	light brown sand	11
K 24	Songshin-tong, Ouyang-myon, Kyongsong-kun, Hamgyong-pukto	light brown sand	1

25	Tokyoun-tong, Ochon-myon, Kyongsong-kun, Hamgyong-pukto	grayish white sand	10
K 26_1	Bipa-tong, Songyong-tong, Unggi-ub, Kyonghung-kun, Hamgyong-pukto	grayish white sand	2
K 26_2	Ungsang-tong, Unggi-ub, Kyong-hung-kun, Hamgyong-pukto	light yellowish brown sand	4
K 26_3	Unggi-tong, Unggi-ub, Kyonghung-kun, Hamgsong-kun, Hamgyong-kun, Hamgyong-pukto	grayish white sand	4
K 27	Sosura-tong, Roso-myon, Kyong-hung-kun, Hamgyong-pukto	grayisy white sand	4

formations are well developed.

Sample 76, near the mouth of the Dai River; Samples 309A~C, at three points on the east coast of Uchino-ura, about 500 m, 700 m and 900 m north of the mouth of the Uchinoura River; Samples 309D, E, at two points on the west coast, about 700 m and 1300 m north of the same river; Sample 75, on the east coast of Hosono-ura; Samples 307A~E, at five points around Tsunashirazu-ura.

Table 3. Summary of Table 1 and 2.

Number of samples		Cu content (10^{-4}%)	
		Range	Average
Total samples from Kii Peninsula	35	trace ~ 117	23
Sands	14	1 ~ 108	17
Muds	21	trace ~ 117	27
Total samples from Honshū (excluding Kii)	101	trace ~ 240	19
Sands	75	trace ~ 172	13
Mud	26	4 ~ 240	37
Total samples from Korea	30	1 ~ 64	14
sands	11	1 ~ 11	5
Muds	19	3 ~ 64	20

Of these deposits, the copper content is relatively high in Sample 309E, but low in most of others, especially in Samples 309B~D.

Among the deposits of other coasts, copper is relatively high in Sample 74 and low in Sample 78.

Next, as for Mie Prefecture, it is noticeable that copper is exceedingly

high in most of the Samples 310A~E from Tōshishima, an island mainly composed of green rocks and small amounts of perioditite and serpentine. These samples were collected along the bay head of Kariya-ura at intervals of about 150 m. Of the Samples 305A~D from Nishiki Bay where Mesozoic formations predominate, it is seen that the copper content is exceedingly high in Sample 305B and relatively high in Sample 305A. Sample 305A was collected at Daimyojinhana; Sample 305B, at the point about 400 m west of Fujihana; Samples 305C, D, at two points about 300 m and 500 m northeast of Ryūgūhana.

Of the samples from the other coasts of Mie, copper is relatively high in Sample 80, while it is exceedingly low in Sample 79.

Now, as for the deposits from places outside the Kii Peninsula, it is seen from Table 2 that the copper content is exceedingly high in Sample 31 collected in Hiroshima Prefecture, Sample 69 from Tottori and Sample 82 from Okayama, and remarkably high in Sample 50 from Okayama, Sample 87 from Kanagawa, Sample 93 from Miyagi and Sample K 11 from Cholla-namdo.

Sumarizing the data in Tables 1 and 2, the authors obtained the figures shown in Table 3, which shows that the average copper content of the total samples of Kii is higher than that of the other Honshū samples and of the Korean samples and that the same thing is true about the average for sands alone. The average for the muds of Kii is higher than that for the Korean muds, and lower than that of the Honshū (excluding Kii) muds. And it is observed that the average copper content is higher in muds than in sands everywhere.

Between the amounts of copper and the other constituents, there seems to be no definite relation applicable to all the samples*, though in deep-sea deposits such as red clay, copper and manganese contents are said to vary side by side owing to the fact that the copper is adsorbed by colloidal particles of manganese in sea-water and deposited together with the latter[3].

(2) Relation between the Copper Content and the Geology.

Between the copper content of most of these deposits and the geology of the land adjacent to the locations sampled, it is difficult to find definite relationship, because the deposits may have been carried to the sites from some remote places of origin by the river water and/or sea currents. Therefore, the authors collected some deposits from a number of small islands* having relatively simple geological structure and unlikely to be

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* The relation between copper and other constituents was investigated with 139 samples whose total analyses had been completed.

Table 4. Copper content of the shallow-water

Locality	Geology**	Type of deposits
Hiroshima, Kagawa-ken	Granites	Grayish white sand
Nakashima, Ehime-ken	Granites	light brown sand
Ogishima, Kagawa-ken	Granites (Sanukite)	light brown sand
Momoshima, Hiroshima-ken	Granites	light brown sand
Yokoshima, Hiroshima-ken	Granites	light brown sand
Okinoshima, Kōchi-ken	Granites	grayish brown sand
Kogoshima, Ehime-ken	Granites	brown sand
Kōnoshima, Okayama-ken	Quartz-porphyry	light brown sand
Tashima, Hiroshima-ken	Quartz-porphyry (Granites, Ryōke metamorphics)	greenish sandy mud
Hēgunshima, Yamaguchi-ken	Pyroxene-andesite	grayish brown sand
Kajishima, Ehime-ken	Norite	light blackish gray sand
Kasatoshima, Yamaguchi-ken	Ryōke metamorphics (Granites)	grayish brown sandy mud
Ōtsushima, Yamaguchi-ken	Sangun metamorphics (Granites)	blackish green sand
Takashima, Ōita-ken	Sanbagawa metamorphics	grayish white sand
Nushima, Hyōgo-ken	Greenschist, Black phyllite	light brown sand
Shishishima, Kagawa-ken	Upper Paleozoic formations	yellowish brown sand
Mutsukishima, Ehime-ken	Upper Paleozoic formations (Granites)	brown sand
Ōnyūshima, Ōita-ken	Mesozoic formations	brown sand
Shimoniizu-mura, Ōita-ken	Mesozoic formations	blackish gray sand
Sugari, Owashi-shi, Mie-ken	Mesozoic formations	blackish gray sand
Tobishima, Yamagata-ken	Tertiary formations	blackish gray sand
Higashitonda-mura, Wakayama-ken	Tertiary formations	light blackish gray
Himagashima, Aichi-ken	Tertiary formations	light grayish brown sand

* Three capes are also included.

** Only the predominant rocks and formations are shown. The parentheses are sampled.

deposits collected from various small islands.*

Composite of	Cu 10^{-4}%	SiO^2 %	Fe_2O_3 %	Al_2O_3 %	MnO %	CaO %	MgO %	CO %
5	trace	82.92	0.56	9.23	trace	0.74	0.33	——
5	3	79.28	1.26	11.01	0.01	1.09	0.34	——
5	4	77.49	1.97	12.16	0.03	2.23	0.24	——
4	4	75.81	2.34	12.21	0.04	1.69	0.40	——
5	4	76.21	2.49	14.77	0.03	1.32	0.25	——
5	4	73.96	3.08	10.40	0.04	3.76	0.46	2.33
3	4	70.62	4.28	12.98	0.11	2.85	1.14	1.66
5	6	79.24	1.56	9.74	0.02	2.57	0.56	1.28
5	9	75.87	2.02	11.52	0.03	0.90	0.49	——
2	8	71.20	2.98	13.49	0.04	6.92	1.87	——
5	9	52.64	8.25	20.06	0.18	9.69	4.58	0.52
4	19	79.36	3.05	6.82	0.11	2.82	1.12	1.58
2	18	47.48	6.14	12.31	0.12	15.95	2.74	8.28
5	25	70.02	2.87	9.51	0.06	7.05	1.86	4.01
5	11	74.26	2.16	7.07	0.06	5.62	0.74	3.86
5	3	87.54	1.00	5.77	0.04	1.19	0.21	——
2	7	79.25	1.02	10.05	0.01	2.13	0.52	——
4	15	76.42	2.99	10.95	0.03	1.80		0.50
5	30	70.67	5.21	13.37	0.08	0.76	1.10	——
4	19	72.20	3.33	11.27	0.04	3.45	0.65	1.20
4	2	57.69	3.69	14.82	0.05	8.56	2.20	5.14
4	14	56.25	2.76	7.15	0.01	15.27	1.25	11.28
5	10	77.54	1.79	8.77	0.01	3.83	0.51	2.18

for the rocks which distribute in the land areas relatively far from the locatition

influenced by the geology of remote places, and analysed a composite of 2~5 kinds of deposits from each island.

The analytical results are shown in Table 4 on the sea-salt-free and dry basis.

In the deposits collected at Hiroshima~Tashima where acidic igneous rocks predominate, the copper content ranges trace~9×10^{-4}%. The deposits from Heigun and Kajishima, where basic rocks predominate, show no conspicuous difference in the copper content compared with the deposits from the preceeding islands. As for the metamorphic rocks, copper is relatively high in most of the samples. And of the sedimentary rocks, it is high in those of Mesozoic formations which are mostly composed of shale perhaps deposited in rather deep seas, while it is relatively low in the Tertiary formations and still lower in Paleozoic formations.

Results of Table 4 are summarized in Table 5.

Table 5. Copper content and the geology (summary of Table 4).

Geology	Number of samples	Cu content (10^{-4}%)	
		Range	Average
Igneous rocks			
Acidic rocks	9	trace ~ 9	4
Basic rocks	2	8 ~ 9	9
Metamorphic rocks			
Gneisses	1	—	19
Crystalline schists	3	11 ~ 25	18
Sedimentary rocks			
Upper Paleozoic formations	2	3 ~ 7	5
Mesozoic formations	3	15 ~ 30	21
Tertiary formatiohs	3	2 ~ 14	9

The authors wish to express their thanks to Messrs. I. Kitanishi, S. Tanaka, G. Ikebe, S. Teramae, S. Gayō, M. Iesaki, K. Nishi and F. Miyamura who presented us many valuable samples from the Kii Peninsula.

* Three capes are also included.

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MARINE ALGAE OF THE KII PENINSULA, WITH SPECIAL REFERENCE TO THE CORALLINACEAE (Preliminary report)

By Sokiti Segawa

(Fisheries Laboratory, Faculty of Agriculture, Kyushu University)

The author made phycological surveys at Tanabe, Shirahama, Susami and Shio-no-misaki in September, 1956, and at Shio-no-misaki again in February, 1957. The materials collected there are, at present, still under investigation. Among them, some corallinaceous algae are listed below and brief remarks are given especially on the distribution of these algae in this district.

In the course of this study, the author has been much indebted to Mr. **M. Higaki** in his laboratory, for the arrangement of the articulated corallines, and to Mr. **T. Yamamoto** in the Seto Marine Biological laboratory, Kyoto University, for the collection of the materials.

Melobesioideae

47 samples are under investigation. Among them, the following species are very common and noteworthy.

1. *Goniolithon misakiensis* **Foslie** (Fig. 1)

Material can be referred to this species than to *G. versabile* **Foslie,** because the cells are generally large in size.

2. *Lithophyllum okamurai* **Foslie** nom. jap.: Hira-ibo

Characteristic thalli growing on rocks or stones are found abundantly in this district.

3. *Porolithon* sp. (Fig. 2)

The thalli are crustaceous, encrusting the small stone. In appearance, it resembles very much to *Lithophyllum shioense* **Foslie.** The structure is, however, very different from that of *Lithophyllum,* and the mode of connection between cells belonging to different filaments is transverse fusion. This species seems to be *Porolithon,* although no heterocyst has been observed in the tissue. It is noteworthy that the author has not been able to collect *L. shioense* from the shore near the light-house of Shio-no-misaki, the type locality of the species, in spite of his efforts.

4. *Porolithon* sp. (Fig. 3)

This species has wart-like protuberances and forms a remarkable

community on the rocks of littoral belt of Susami, Shio-no-misaki etc. Heterocysts are found forming a horizontal row. *Porolithon* bearing the above mentioned appearance has not been described and seems to be new to science.

Corallinoideae

5. *Amphiroa rigida*

Materials referable to this species were collected here and there in this district. The thalli bearing cylindrical intergenicula, agree well to the specimens collected from Shikoku and southern Kyushu.

6. *Amphiroa ephedrayae* **Decaisne** nom. jap.: Maō-kaninote
7. *Amphiroa dilatata* **Lamouroux** nom. jap.: Kani-no-te
8. *Amphiroa abberans* **Yendo** nom. jop.: Fusa-kaninote
9. *Amphiroa crassissima* **Yendo** nom. jap.: Heritori-kaninote
10. *Corallina pilulifera* **Postels** et **Ruprecht** nom. jap.: Piri-hiba
    f. *filiformis* **Ruprecht**
    f. *sororia* **Ruprecht**

These two forms of *C. pilulifera* were commonly collected from the district.

11. *Jania ungulata* YENDO nom. jop.: Sakibiro-mosazuki
12. *Jania* sp.

The author has not been able to refer the present material to *J. adhaerens* nor *J. decussato-dichotoma*. There is need of revised studies systematically on *J. adhaerens* and its allies.

Generally speaking, the corallinaceous flora of the Kii Peninsula is not so different from that of Tosa province or southern Kyushu, and cannot be said to be rich in number of species. The presence of communities of *Porolithon* spp. seems to be one of the characteristics in this district. However, these respects must be confirmed after more extensive surveys made in spring and summer, the seasons of corallinaceous algae.

(March, 1957)

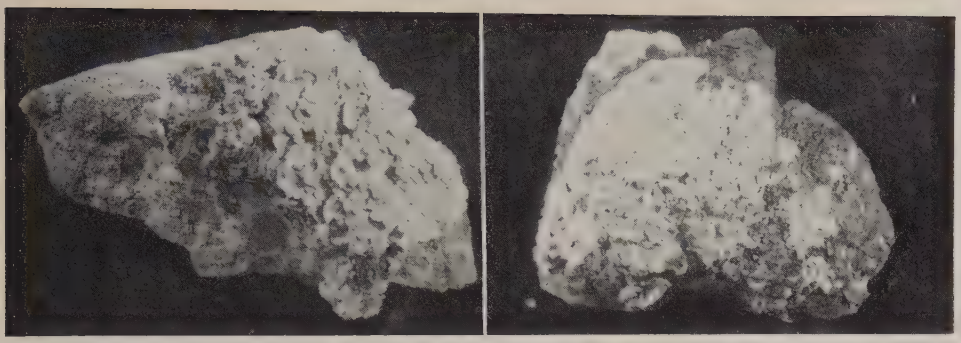

Fig. 1. *Goniolithon misakiensis* FOSLIE (×4/5)

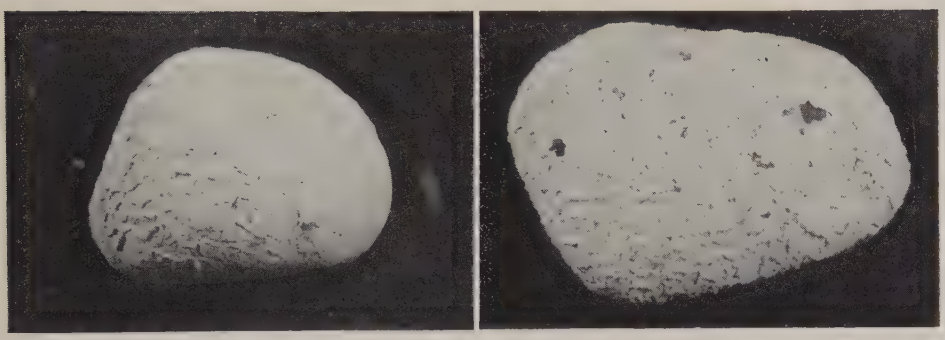

Fig. 2. *Porolithon* sp. (×4/5)

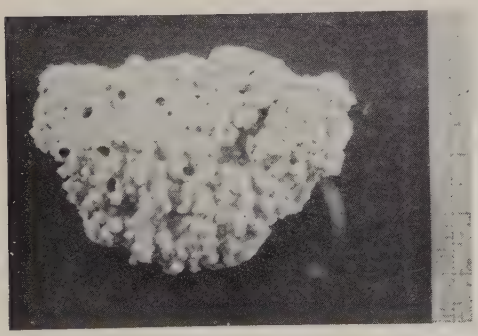

Fig. 3. *Porolithon* sp. (×4/5)

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STUDIES ON THE LUMINOUS ORGANISMS FOUND IN WATERS ADJACENT TO THE PACIFIC COASTS OF JAPAN

Report II.

By Yata Haneda

(Yokosuka City Museum and Jikeikai School of Medicine)

The following reports on luminous organisms illustrates some of the results obtained during 1956 to 1957, in the cooperative biological and oceanographic researches in the waters adjacent to the Pacific coasts of Japan through the financial aid of the Committee on Marine Resources of the Japanese National Commission for UNESCO.

As a member of this research group, the author has also been investigating both coastal and deep water luminous organisms. From 1956 to 1957 the research area was limited mostly to Shima and Kii Peninsulas. The research center and the collecting places were as follows:

Seto marine biological station; Owase base port of deep water trawl fishing boats; and the Mikawa-miya fishing market.

Research on the following problems concerning luminous organisms was carried on: Structure of luminous organ; anatomy and histology of luminous organ; type of luminous organ; luminous phenomena of organisms in living condition; behavior of luminous organisms; distribution of luminous organisms; luminous symbiosis and biochemical reaction of luminous substances.

The author wishes to describe here only some of the more interesting organisms studied.

(1) New types of luminous organ in fish discovered.

In 1950, the author reported a new type of luminous organ in fish, i.e., the indirect emission type. In the present research two other luminous fish organ of the same type were detected in two species hitehrto unsuspected to being luminous, i.e., *Paratrachichthys prosthemius* **Jordan** et **Fowler**, of the family Trachichthyidae and *Parapriacanthus beryciformis* **Franz** of the family Pempheridae.

Some of the results of the study of the luminous organ of *Paratrachichthys prosthemius* were given in the Yokosuka City Museum Science Report Nr. 2, March 1957. The complete luminous organ of *Paratra-*

chichthys prosthemius consists of three, or possibly four components.

1) luminous gland and its lens and opening; 2) cloudy translucent keel muscle; 3) filiform body which extends backward from the luminous gland and possibly 4) a shutter for the light spot which may be either opened or closed by chromatophores. In the gland, bacteria occur in the film of material which lie on the inner surface of the epithelial cells.

Two luminous organs were recently detected by the author in specimens of the latter type, *Parapriacanthus beryciformis* which were obtained at the Shimoda fish market, Izu Peninsula. *Parapriacanthus beryciformis* of the family Pempheridae, is a small fish common to the coastal waters of Boshu, Izu and Kii Peninsulas and more southern Japanese waters.

Externally this fish does not present any unusual features, and it is only by careful observation of the living fish by night that its luminosity becomes apparent. Both sources of light are luminous ducts which lie under a layer of translucent muscle tissue on the ventral side, between the pectoral fins and the anus. The more anterior of these two luminous organs is a V-shaped, thin, white, closed tubular structure, while the other extends mid-ventrally to the rectum with which it communicates through a small pore. In a living specimen, pressing a finger against this latter organ causes the emission of a visibly luminous liquid from the anus. In the specimens of 75 mm. total length, the V-shaped thoracic duct measured 10 mm. long, 1.0 mm. width, 0.2 mm. thickness and the anal duct 7 mm. long, 1 mm. width, 0.2 mm. thickness. The cloudy translucent part of the keel muscle, which part lies entirely before the anus, is very similar to that found in *Acropoma japonicum, Paratrachichthys prosthemius* and several fish of the family Leiognathidae. The light, from the thoracic luminous duct source, diffuse through these muscle areas, from whence it is externally visible. The keel muscle serve as a lens.

Therefore the complete luminous organ of this fish consists of above mentioned three components: i.e. thoracic luminous organ, anal luminous organ and cloudy translucent keel muscle. Concerning the V-shaped luminous organ, in outward appearance it is very similar to the U-shaped luminous gland of *Acropoma japonicum*, in which gland symbiotic luminous bacteria live, but in its structure and also in the contents of the gland itself, the similarity ends. The test cultivation of luminous bacteria from the luminous ducts of this fish were made by the usual bacteriological techniques from 10 of this fish, and were obtained negative results in all cases. The Luciferin-Luciferase reactions obtained of the luminous substances of both luminous ducts were positive. It is most important to note that this is the first time that a positive Luciferine-Luciferase re-

action has been obtained of a luminous fish substance. A more detailed report on this fish, by Dr. Frank H. **Johnson** and the author, will be published shortly in the Proceedings of the American Academy of Science.

(2) First recorded observation of luminescence among Lamellibranchs in Japan.

For many years it was thought that *Pholas dactylus* was the only luminous species among lamellibranchs, but the author (1939) has found another bivalve, *Rocellaria (Gastrochaena) grandis* from the reefs of the Palao Islands, which also produces a luminous secretion.

Prior to the study under consideration, no recorded observations of luminescence in this family had existed in Japan. At Seto marine biological station the author collected and observed living specimens of several species of boring shells, and found *Rocellaria grandis* to be the only luminous species among them. *Rocellaria grandis* has a pair of luminous stripes on the mantle along the pallial lines and produces a luminous secretion which fills the mantle cavity and spouts from the siphon when irritated. The dried luminous tissue recovers its luminosity when moistened and the Luciferin-Luciferase reaction is positive.

(3) On newly discovered luminous fish of the family Paralepididae.

The *Lestidium prolixum* **Harry** of the family Paralepididae is a deep water fish found in the waters of Kumanonada and Suruga Bay. The specimens studied were collected from the Owase fish market, and presented by Mr. Tamotsu **Iwai** of the fisheries department of Kyoto University. It averages about 260 mm. in length, and the body is whitish and translucent. Extending on a median line from a point near the anus to the forepart of the fish is a long yellowish and thin structure to form one organ. In the 260 mm. specimen, this yellowish structure measured 102 mm. in length, 1.0 mm. in breadth.

In appearance of this structure closely resemble the luminous gland of *Acropoma japonicum*. Investigation reveals that this organ neither connects with the rectum, nor opens outward to the body exterior. Also the structure of this organ differs greatly from that of *Acropoma japonicum*. A transparent, long, and muscular substance extends on a median line from the anus to the forepart of the fish, and serves as a lens.

In his anatomical and histological observations, the author was not been able to ascertain any actual light emission from the organs described; recently however, two fresh specimens of the different species of the same genus of fish, *Lestidium japonicum* **Tanaka** were taken from Manazuru hourbor, Kanagawa Prefecture and kindly presented to the author by Dr. Tokiharu **Abe** of the Tokaiku Fisheries Laboratory. Consequently the author was able to observe the actual light emission of these

yellowish structures in the dark, thus confirming that this fish is a new type of luminous fish, possessing self-luminous substances.

The long yellowish structure of this fish separated in two long structures, which are joined together at each end, to form one organ. In the 175 mm. specimen, these yellowish structures measured 60 mm. in length 0.4 mm. in breadth.

Details of anatomical and histological studies conducted upon this species will be presented in a future report.

Acknowledgment:

To the following people the author must express his sincere gratitude and appreciation:

To Professors Shinkichi **Hatai** and Koji **Hidaka** of the Committee on the Research of Marine Resources sponsored by the Japanese National Commission for UNESCO, for having given him the opportunity to carry out this present work; to Dr. Fujio **Uchinomi** of the Seto Marine Biological Station who provided the facilities required for the pursuit of this work; to Dr. Tadashige **Habe** of the Amakusa Marine Biological Station who gave in valuable advice and assisted collecting shell specimens; to **Mr.** Tamotsu **Iwai**, who suggested the possibility of luminescence in *Lestidium prolixum* and supplied valuable specimens of this fish; and to Dr. Tokiharu **Abe**, who gave invaluable advice and also kindly supplied specimens of *Lestidium japonicum*.

The author would also like to express his warmest appreciation to the Committee on the Research of Marine Resources for financial aid.

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TWO NEW SUBSPECIES OF FISHES FROM THE PATH OF THE "KURO-SHIWO"

By Tokiharu Abe

(Tokai Regional Fisheries Research Laboratory, and Zoological Institute, Faculty of Science, University of Tokyo)

During the fiscal year 1956 (April, 1956-March, 1957), the writer made trips* to Kii Peninsula (south of Osaka) collecting fishes and gathering data about the annual changes in the elements of the piscifauna and in the course of the "Kuro-shiwo". As expected from his studies continued since 1950 on the fishes of the waters between the Bonin Islands and Tokyo which are also directly in the path of the "Kuro-shiwo", the constituents of the piscifauna of Kii Peninsula seem to change considerably from year to year at least partly affected by the annual fluctuation in the course and strength of this current. Leaving for future work the study of these annual changes, the writer published during the fiscal year the following papers on the fishes from the path of the "Kuro-shiwo":

1. In Tomiyama and Abe's Figures and descriptions of the fishes of Japan, vol. liv, pp. 1095-1114, pls. 218 and 219. August, 1956.
2. Notes on some edible marine fishes collected between the Bonin Islands and the mouth of Sagami Bay. I. Bull. Tokai Regional Fisheries Research Laboratory, no. 14, pp. 15-19. (With Y. Takashima). September, 1956.
3. In Tomiyama and Abe's Figures and descriptions of the fishes of Japan, vol. lv, pp. 1115-1127, pls. 220 and 221. November, 1956.
4. In Tomiyama and Abe's Figures and descriptions of the fishes of Japan, vol. lvi, pp. 1141-1163, pls. 226 and 227. February, 1957.

In the present paper the writer introduces two new subspecies of fishes from the path of the "Kuro-shiwo". One of them, though well known to some fish-dealers, seems to have been overlooked by predecessors probably because of its resemblance in beautiful coloration to a congener, *Decapterus* russelli (Rüppell). The other has been recorded erroneously under the name of Balistes nycterias (Jordan & Evermann).

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* Aided by a grant-in-aid from the Japanese Naitonal Commission for UNESCO. The writer wishes to express here his sincere thanks to the Commission and Mr. B. Araya (Japanese Association for the Advancement of Science) for their courtesy, and to Miss Y. Takashima for help in preparing this report.

1. *Decapteus kurroides aka-adsi,* New Subspecies

"Aka-adsi" (new Japanese name)*

Material examined.—Holotype (Cat. No. 49749, Zooligical Institute, Faculty of Science, University of Tokyo=Cat. No. 10697, Abe), presented by Mr. Hikoe Isokawa (Itō City), who collected the specimen at the Market of Itō in compliance with the writer's request. According to him, it was taken by a trap net near Hatsushima (east of Atami; west of Sagami Bay) on April 19, 1956, and some 1 kg of this form were included among some 20 kg of *Trachurus japonicus* (Temminck & Schlegel). The writer wishes to express here his sincere thanks to him for the co-operation. He is a fish-dealer at the Market of Itō, and makes dried mackerel scads (members of *Decapterus*). Two paratypes (Cat. Nos. '57-120, '57-265, Abe) (*vide* foot-note on p. 000).

Description of the holotype.—Total length 218 mm, fork length 202 mm and standard length (from snout tip to hind end of vertebral column) 182 mm. The following measurements are given in hundredths of the standard length: Greatest depth of body 23.6, greatest breadth of body (at pectoral origins) 15.4, least depth of caudal peduncle 3.8, length of head 28.6 (left) and 28.0 (right), horizontal diameter of orbit (adipose eyelid removed) *ca.* 8.5 (right), length of snout *ca.* 8.5 (right), bony interorbital breadth above eye-centers 8.2, length of longest gill-rakers on 1st arch 4.7 (right), height of largest scute 4.4 or 4.5, length of longest (3rd) dorsal spine 14.8, length of longest soft fin-ray of 2nd dorsal 11.6. length of 1st and 2nd anal spines 4.5, length of longest soft fin-ray of anal 10.5, length of longest (4th) pectoral fin-ray 25.3 (left) and 25.8 (right; 4th and 5th fin-rays of same length), length of ventral spine 7.1 (left and right), length of longest (outermost) ventral fin-ray 13.5 (left and right).

D. VIII, 29 (=i+28; last fin-ray bifid to base), 1 finlet. A. II, 24 (=i+23; last fin-ray bifid to base), 1 finlet. P. 21 (=ii+19) on both sides. V. I 5 (all fin-rays branched).

The body is slightly compressed and fairly high. The pectoral fins are long, slightly shorter than the head. The lateral line becomes straight below the 12th dorsal fin-ray. The number of scales in the lateral line is *ca.* 84 on the left side, of which the posterior 35 are scutes entirely occupying the straight part of the lateral line. On the right side, the

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* Meaning red *Trachurus*. Fish dealers in Izu Peninsula (west of Sagami Bay) call this fish "Aka-adsi" believing that it is a variety of *Trachurus japonicus* (Temminck & Schlegel) because of its deep body and long pectoral fins. The writer adopts here this vernacular name as the authorized Japanese name of this new fish.

number of scales in the lateral line is *ca.* 86, and the number of the scutes which begin from the anteriormost point of the straight portion of the lateral line is 36. The distance (measured parallel to the longitudinal axis of body) from the origin of the 2nd dorsal fin to the turning point of the lateral line (where it becomes straight) is smaller (29 mm on the left side, and 26 mm on the right) than the distance (measured parallel to the longitudinal axis of body) from the latter point to the base of the hindmost dorsal fin-ray (not of the finlet) (38 mm on the left side, and 42 mm on the right).

The number of gills is 4. There is a slit behind the 4th gill. The pseudobranchiae are well developed. The number of the gill-rakers on the right 1st arch is 12+30, the uppermost several rakers of the lower limb being the longest. The jaw teeth are small, slightly curved, and arranged mostly in a single row; anteriority they are in 2 or 3 rows. The teeth of the tongue, vomer and palatines are very small, and arranged in a longitudinal row on each of the bones, the width of the row being the greatest on the tongue. There are no teeth on the head of vomer*. The hind end of the maxillary is weakly concave, and nearly reaches the vertical through

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* After the present paper had been submitted written in Japanese to the Japanese National Commission for UNESCO, the following two specimens of the present new sub-species were examined:

Cat. No. '57—120, Abe. Collected at the Central Wholesale Market of Tokyo on April 25, 1957. Total length 230 mm, fork length 207 mm, standard length 193 mm. D. VIII, 30 (=i+29), 1 finlet. A. II, 24 (=i+23), 1 finlet. The pectoral fins are very slightly shorter than the head. The teeth on the palatines and tongue are arranged in narrow bands as in the holotype. The vomer has no teeth on its head. A narrow row of villiform teeth is present in the median line of the vomer as in the holotype.

Cat. No. '57—265, Abe. Collected at the Central Wholesale Market of Tokyo on July 26, 1957. Total length 220 mm, fork length 198 mm, standard length 183 mm. D. VIII, 30 (=i+29), finlet. A. 25 (=i+24), 1 finlet. Length of head 50.5 mm (left) and 51.0 mm (right), length of pectoral fin 47 mm (left) and 48 mm (right). There is a very narrow row of villiform teeth on either palatine as in the holotype. The row, or band, of the villiform teeth along the middle of the tongue is fainly wide as in the holotype. The vomer has a fairly long, narrow row of villiform teeth in the median line as in the holotype, but at the anteriormost projection of the bone is a very small spot bearing a few teeth which is connected by a single tooth with the median row behind, and there are a pair of very small patch of villiform teeth behind the single tooth. The line connecting the centers of these patches is perpendicular to the longitudinal row of the vomerine teeth and passes the anterior end of the latter. Either patch is close to the oblique margin of either side of the head of the vomer. The coloration prior to preservation of the two paratypes mentioned here was the same as that of the holotype.

the anterior margin of the eye. The scaled area on top of the head anteriorly reaches slightly beyond the anterior margins of the orbits. There is a long keel from behind the posterior nostrils to the origin of the spinous dorsal fin.

Prior to preservation, the specimen was very colorful like *Decapterus russelli* (Rüppell). The dorsal, caudal and pectoral fins and the finlets were reddish, and the back was greenish blue. The head was reddish dorsally, and shined like platinum ventrally. The antero-dorsal corner of the 2nd dorsal fin and the hind margin of the caudal fin were narrowly white. The ventral and anal fins were mostly hyaline, the fin-rays of the former being light yellowish pink. The tongue shined like platinum bearing bluish tint. The color in formalin is dark blue above, and whitish below, the fins being pale. The black blotch on the operculum is as distinct as in fresh state.

Relationships.—The present new subspecies is close to *Decapterus kurroides* Bleeker, *D. dayi* Wakiya and, in lesser degree, to *D. maruadsi* (Temminck & Schlegel), all of which were lumped by Bertin & Dolfus (1948) under the name of *D. kiliche* Cuvier. The type of *kiliche* (Coll. Mus. Paris, no. 5848) was collected in Pondichery. It measures 155 mm in total length and 145 mm in length without caudal, and differs from the present new subspecies in having shorter pectoral fins and in the position of the anteriormost scute in the lateral line. In body proportions, the present new subspecies resembles *dayi*, but the number of the fin-rays in the dorsal and anal, and the size of the largest scute are smaller in the former than in the latter. From *D. kurroides kurroides* the present new subspecies differs in the weak dention on the head of the vomer and in the coloration (in the former, the fins are not reddish, but yellow or violet). *D. maruadsi* differs from the present new subspecies considerably in the number of the fin-rays of the dorsal and anal, and in coloration. Fish-dealers call *maruadsi* "Ao-adsi", which means blue *Trachurus*.

Finally, *D. russelli* resembles the present subspecies at first sight, both being very colorful, but they differ greatly from one another in body proportions, dentition, length of the pectoral fins and the position of the anteriormost scute.

II. *Balistes vidua kamoharai*, New Name

"Irezumi-mongara"

Balistes nycterias Kamohara (not of Jordan & Evermann), 1934, p. 461. Urado (in Kōchi City). —— *Id.*, 1940, pp. 36 & 37, fig. 14. Without locality. The figure is based on a specimen measuring *ca.* 13

cm in total length (probably the same specimen recorded in the work of the same author mentioned just above). ——— *Id.*, 1942, p. 167. Kii Peninsula.

Balistes sp. MATSUBARA, 1955, p. 991. Reference.

As pointed out by Matsubara (1955), this form differs from *nycterias* in having eight dark lines radiating from the eye. The present writer has examined two specimens of *kamoharai* (Cat. Nos. 42402, 44407, Zool. Inst., Fac. Sci., Univ. Tokyo) measuring 123 and 135 mm in total length, and found that it differs from *nycterias* in having conspicuous hooks on the 1st dorsal spine and in having lesser scale rows in lengthwise series, and that it is close to *Balistes vidua* Solander of which he has examined eight specimens. Another specimen (Cat. Nos. 23700, Zool. Inst., Fac. Sci., Univ. Tokyo), collected in Wakayama Prefecture (Kii Peninsula), has five indistinct dark lines radiating from the eye. In this specimen, only the dorsal margin of the dorsal fin is black, and the 1st dorsal spine lacks hooks. In the absence of ample material, the writer is not able to state for certain whether *kamoharai* and *vidua* represent the two sexes of a single form or not. He thinks it advisable to give for the time being a new name to Kamohara's *nycterias*.

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A PRELIMINARY LIST OF THE MARINE ALGAE FROM THE SHORES OF THE KII PENINSULA

By Yukio Yamada

Since 1955 the writer has been engaging in elucidating the marine flora of the Kii Peninsula, and up to the present time 254 species belonging to 105 genera (48 Families) have been recorded, all of which are included in the red, the brown and the green algae. They all are limited to those species which the writer has been able to determine personally. Among them one species of *Chrysymenia* and one of *Hypnea* seem to be new to science which will be described elsewhere. One tropical red alga, *Titanophora weberae* Boerg. was found for the first time on our coast, cast ashore at the Cape Shionomisaki, the southernmost point of the peninsula.

The writer is very grateful to Messrs. T. Yamamoto and C. Morishima for placing their specimens at his disposal.

RHODOPHYCEAE

Protoflorideae

Fam. Bangiaceae

Bangia fuscopurpurea Lyngb.

Porphyra suborbiculata Kjellm.

Florideae

Nemalionales

Fam. Halminthocladiaceae

Helminthocladia australis Harv.

Liagora ceranoides J. Ag.

Liagora farinosa Lamx.

Nemalion multifidum J. Ag.

Nemalion pulvinatum Grun.

Fam. Bonnemaisoniaceae

Asparagopsis hamifera Okam.

Delisea pulchra Mont.

Fam. Chaetangiaceae

Actinotrichia rigida Decne.

Galaxaura arborea Kjellm.

Galaxaura cuculligera Kjellm.

Galaxaura elongata J. Ag.

Galaxaura falcata Kjellm.

Galaxaura fastigiata Decne.

Galaxaura fruticulosa Kjellm.

Galaxaura hystrix Kjellm.

Galaxaura kjellmanii Weber van Bosse

Galaxaura papillata Kjellm.

Galaxaura robusta Kjellm.

Galaxaura sp.

Gloiophloea okamurai Setch.

Scinaia Cottonii Setch.

Scinaia japonica Setchell

Gelidiales

Fam. Gelidiaceae

Acanthopeltis japonica Okam.

Gelidiella acerosa Feld. et Hamel

Gelidium amansii Lam.
Gelidium divaricatum Martens
Gelidium japonicum Okam.
Gelidium linoides Kütz.
Gelidium pacificum Okam.
Gelidium pusillum Le Jolis f. foliaceum
Gelidium subcostatum Okam.
Gelidium tenue Okam.
Gelidium vagum Okam.
Pterocladia tenuis Okam.
Pterocladia nana Okam.

Cryptonemiales

Fam. Dumontiaceae
Dudresnaya japonica Okam.
Fam. Rhizophyllidaceae
Chondrococeus hornemanni Schm.
Fam. Squamariaceae
Peyssonnelia rubra J. Ag.
Fam. Grateloupiaceae
Aeodes lanceolata Okam.
Aeodes lanceolata f. tenuis Okam.
Carpopeltis affinis Okam.
Carpopeltis angusta Okam.
Carpopeltis articulata Okam.
Carpopeltis crispata Okam.
Carpopeltis divaricata Okam.
Carpopeltis flabellata Okam.
Carpopeltis okamurai Arwids.
Carpopeltis rigida Schm.
Grateloupia elliptica Holmes
Grateloupia filicina Ag.
Grateloupia filicina f. lomentaria Howe
Grateloupia imbricata Holm.
Grateloupia livida Yamada
Grateloupia okamurai Yam.
Grateloupia ramosissima Okam.
Halymenia acuminata Okam.
Halymenia agardhii De Toni
Halymenia dilatata Zanard.
Halymenia sp.
Polyopes polyideoides Okam.
Titanophora webereae Boerg.
Fam. Endocladiaceae
Gloiopeltis complanata Yam.
Gloiopeltis tenax J. Ag.
Fam. Callymeniaceae
Callophyllis adhaerens Yam.
Callophyllis japonica Okam.
Callymenia perforata J. Ag.
Callymenia sessilis Okam.
Callymenia sp.

Gigartinales

Fam. Calosiphoniaceae
Calosiphonia vermicularis Schm.
Fam. Nemastomaceae
Bertholdia japonica (Okam.) Segawa
Nemastoma lancifolia Okam.
Platoma izunosimensis Segawa
Schyzymenia dubyi J. Ag.
Fam. Sebdeniaceae
Sebdenia okamurai Yam.
Fam. Solieriaceae
Eucheuma serra J. Ag.
Meristotheca papulosa J. Ag.
Solieria robusta Kylin
Fam. Typneaeceae
Hypnea charoides Lamx.
Hypnea japonica Tanaka
Hypnea nidulans Setch.
Hypnea variabilis Okam.
Hypnea sp. n.
Hypnea sp.
Fam. Plocamiaceae
Plocamium telfairiae Harv.
Fam. Sphaerococcaceae
Caulacanthus okamurai

Yamada

Fam. Sarcodiaceae

Sarcodia ceylanica Harv.

Fam. Gracilariaceae

Ceratodictyon spongiosum Zan.

Gelidiopsis gracilis Kg.

Gelidiopsis repens Schm.

Gracilaria arcuata Zan. ?

Gracilaria chorda Holm.

Gracilaria compressa Grev.

Gracilaria confervoides Grev. ?

Gracilaria gigas Harv.

Gracilaria incurvata Okam.

Gracilaria punctata Yam.

Gracilaria sublittoralis Yam. et Segawa

Gracilaria textorii Sur.

Tylotus lichenoides Okam.

Fam. Phyllophoraceae

Ahnfeltia furcellata Okam.

Ahnfeltia paradoxa Okam.

Gymnogongrus divaricatus Holm.

Gymnogongrus flabelliformis Harv.

Gymnogongrus sp.

Stenogramma interrupta Mont.

Fam. Gigartinaceae

Chondrus ocellatus Holm.

Gigartina intermedia Suring.

Gigartina teedii Lamx.

Gigartina tenella Harv.

Rhodymeniales

Fam. Rhodymeniaceae

Chrysymenia grandis Okam.

Chrysymenia polyglandulosa Okam.

Chrysymenia okamurai Yam. et Seg.

Chrysymenia sp. nov.

Coelarthrum mülleri Boerg.

Rhodymenia intricata Okam.

Rhodymenia liniformis Okam.

Fam. Champiaceae

Champia expana Yendo

Champia parvula J. Ag.

Lomentaria catenata Harv.

Ceramiales

Fam. Ceramiaceae

Callithamnion callophyllidicola Yam.

Ceramium crassum Okam.

Ceramium rubrum J. Ag.

Ceramium tenerrimum Okam.

Euptilota articulata Okam.

Griffithsia sp.

Wrangelia argus Mont.

Wrangelia tagoi Okam. et Seg.

Krangelia sp.

Fam. Delesseriaceae

Acrosorium flabellatum Yam.

Acrosorium uncinatum Kylin

Branchioglossum ciliatum Okam.

Erythroglossum minimum Okam.

Hemineura schmitziana De Toni et Okam.

Martensia australis Harv.

Vanvoorstia coccinea Harv.

Fam. Rhodomelaceae

Acanthophora orientalis J. Ag.

Amansia japonica Okam.

Bostrichia tenella J. Ag.

Chondria armata (Kg.) Okam.

Chondria crassicaulis Harv.

Chondria lancifolia Okam.

Chondria tenuissima Ag.

Digenea simplex Ag.

Isoptera regularis Okam.

Laurencia amabilis Yam. ?

Laurencia cartilaginea Yam. ?

Laurencia forsteri Grev.
Laurencia grevilleana Harv.
Laurencia heterochlada Harv.
Laurencia majuscula Lucas
Laurencia okamurai Yamada
Laurencia undulata Yam.
Laurencia venusta Yam.
Laurencia sp. n. ?
Leveillea jungermannioides Harv.
Polysiphonia savatieri Hariot
Polysiphonia sp.
Pterosiphonia fibrillosa Okam.

PHAEOPHYCEAE

Cutleriales

Fam. Cutleriaceae
Cutleria cylindrica Okam.

Dictyotales

Fam. Dictyotaceae
Dictyota dichotoma Lamx.
Dictyota divaricata Lamx.
Dictyota spinulosa Harv.
Dictyopteris prolifera Okam.
Dictyopteris undulata Okam.
Distromium decumbeus (Okam.) Levring
Homoeostrichus flabellatus Okam.
Pachydictyon coriacea Okam.
Padina arborescens Holmes.
Padina japonica Yamada
Padina minor Yamada
Padina sp.
Pocockiella variegata Papenfuss
Spathoglossum pacificum Yendo
Stipopodium zonale Papenf.
Zonaria diesingiana J. Ag.

Chordariales

Fam. Leathesiaceae
Leathesia difformis Aresch.
Petrospongium rugosum S. et G.
Fam. Chordariaceae
Tinocladia crassa Kylin
Fam. Myriocladiaceae
Myriocladia kuromo Yendo.
Fam. Spermatochnaceae
Nemacystus decipiens Kuck.

Sporochnales

Fam. Sporochnaceae
Carpomitra cabrerae Kg.
Sporochnus scoparius Harv.

Punctariales

Fam. Asperococcaceae
Myelophycus caespitosus Kjellm.
Fam. Scytosiphonaceae
Colpomenia deformans Yam.
Colpomenia sinuosa Derb. et Sol.
Endarachne binghamiae J. Ag.
Hydroclathrus clathratus Howe
Scytosiphon lomentarius J. Ag.
Fam. Ishigeaceae
Ishige Okamurai Yendo
Ishige foliaceae Okam.

Laminariales

Fam. Chordaceae
Chorda filum Lamx.
Fam. Laminariaceae
Eisenia bicyclis Setch.
Undaria undarioides (Yendo) Okam.

Fucales

Fam. Sargassaceae
Cystophyllum sisymbrioides J. Ag.
Sargassum angustifolium J. Ag.
Sargassum assimile Harv.
Saryassum confusum Ag.

Sargassum confusum Ag.
Sargassum duplicatum Ag. ?
Sargassum enerve Ag. ?
Sargassum henslowianum J. Ag. v. condensatum Yam. ?
Sargassum horneri Ag.
Sargassum horneri f. furcato-dentatum Yendo
Sargassum ilicifolium J. Ag. ?
Sargassum kashiwajimanum Yendo
Sargassum kushimotense Yendo
Sargassum micracanthum Yendo
Sargassum nigrifolium Yendo
Sargassum nipponicum Yendo
Sargassum patens Ag.
Sargassum piluliferum Ag.
Sargassum piluliferum var. serratifolium Yam.
Sargassum pinnatifidum Harv.
Sargassum ringgoldianum Harv.
Sargassum sandei Reinb.
Sargassum serratifolium Ag.
Sargassum siliquosum J. Ag.
Sargassum tenuifolium Yamada
Sargassum tortile Ag.
Sargassum tosaense Yendo
Sargassum vulgare J. Ag.
Sargassum Yendoi Ok. et Yam.
Sargassum sp.

CHLOROPHYCEAE

Protococcales

Fam. Chlorococcaceae
Collinsielle japonica (Yendo) Printz.

Chaetophorales

Fam. Ulvaceae
Enteromorpha intestinalis Link.
Enteromorpha linza J. Ag.
Enteromorpha sp. (compressa?)
Letterstedtia japonica Holm.
Ulva conglobata Kjellm. f. densa Kjellm.
Ulva pertusa Kjellm.

Siphonocladiales

Fam. Valoniaceae
Anadyomene wrightii Harv.
Boodlea coacta Mur. et De Toni
Cladophoropsis fasciculatus Boerg.
Dictyosphaeria bokotensis Yamada
Dictyosphaeria cavernosa Boerg.
Microdictyon japonicum Setch.
Struvea delicatula Kg.
Valonia macrophysa Kg.
Valonia ventricosa J. Ag.

Fam. Cladophoraceae
Chaetomorpha crassa Kg.
Cladophora ohkuboana Tolmes
Cladophora wrightiana Harv.

Siphonales

Fam. Bryopsidaceae
Bryopsis plumosa Ag.
Bryopsis sp.

Fam. Caulerpaceae
Caulerpa brachypus Harv.
Caulerpa cupressoides var. disticha Web.
Caulerpa cupressoides var. lycopodium f. elegans Web.
Caulerpa cupressoides var. typica Web.
Caulerpa fergusoni Murrey
Caulerpa okamurai Weber

van Bosse
Caulerpa parvifolia Harv.
Caulerpa peltata Lamx. var. typica Web.
Caulerpa racemosa var. laete-virens Weber
Caulerpa racemosa var. occidentalis Boerg.
Caulerpa webbiana f. tomentella Web.

Fam. Codiaceae
Avrainvillea lacerata J. Ag. f. robustior Gepp
Chlorodesmis formosana Yamada
Codium contractum Kjellm.
Codium cylindricum Holmes
Codium divaricatum Holm.
Codium fragile Sur.
Codium intricatum Okam.
Codium tenue Kg.
Helimeda cuneata Hering.
Udotea pavensis Gepp

Fam. Derbesiaceae
Derbesia sp.

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THE FORMATION OF SULFIDE BY SULFATE-REDUCING BACTERIA IN THE ESTUARINE ZONE OF THE RIVER RECEIVING A LARGE QUANTITY OF ORGANIC DRAINAGE

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Yoshihiko Hata,** and Hideo Miyoshi*
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The importance of marine sulfate-reducing bacteria in the formation of sulfides in the coastal region of the sea which received a large amount of industrial or municipal drainage was discussed in the preceding papers.[1-6]

In the estuarine zone of the river we have also often observed that sulfides occurred in very high concentration. The sulfides found in such an area are generally thought to be due to the bacterial reduction of sulfates which have been supplied by the inflowing water from the sea.[7] However, the mechanism of the participation of sulfate-reducing bacteria in the formation of sulfides in such environments has not been studied in detail.

Such being the case, the present study was undertaken with the aim of elucidating the mechanism of the formation of sulfides by bacteria in the estuarine zone of the river, with a special reference to the influence of the inflow of industrial and municipal drainages upon the sulfides formation in such environments. The ecological study reported here was mainly carried out at the stations properly selected in the Takano River which discharges itself into Maizuru Bay.

Experiment

The stations examined were as shown in Fig. 1. Among these stations five ones (stations 6, 7, 8, 9 and 10) which were located near the mouth of the Takano River more or less received the sea water from Maizuru Bay. Especially at the stations 6 and 7 the chlorinity of the water was nearly comparable to that of sea water.

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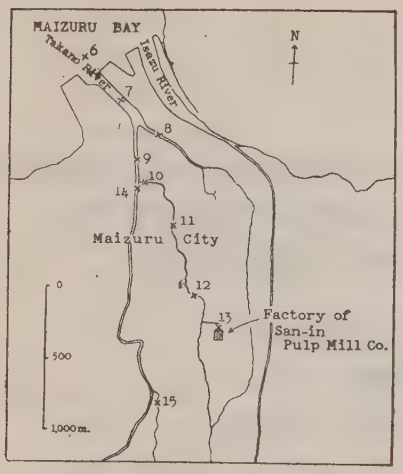

Fig. 1. Stations where the present experiment was carried out.

On the other hand, stations 11, 12, 13, 14 and 15 which were located in the relatively upper course of the river did not receive the water from the sea at all. Accordingly the chlorinity of the waters from these upper stations was very low. The Takano River has received a large quantity of drainages from a pulp factory and Maizuru City. The quantity of drainage which was discharged from the pulp factory into the river was about 1,000 tons per day. This quantity was very large in proportion to the total quantity of the water of the river; the Takano River discharged water into Maizuru Bay in quantity of 0.25 m^3 per second.

The ecological observations were mainly carried out on June 3 and June 4 in 1955, and the additional supplementary examination was carried out on June 4, 1956.

Population counts: The approximate number of sulfate-reducing bacteria in each sample was determined at 30°C, using the media 1 and 6, by use of the extinction dilution method as was described in the preceding paper.[6]

Medium 1: Medium employed for enumerating the marine sulfate-reducing bacteria.

Ca-lactate	3.5 g	K_2HPO_4	0.2
Beef-extract	1.0	$FeSO_4 \cdot 7H_2O$	0.2
Peptone	2.0	Agar	3.0
L-Ascorbic acid*	0.1	Filtered sea water	1,000 ml.
$MgSO_4 \cdot 7H_2O$	0.2	pH	7.5

Medium 6: Medium employed for enumerating sulfate-reducing bacteria of non-marine origin.

Ca-lactate	3.5 g	K_3HPO_4	0.5
Beef-extract	1.0	$FeSO_4 \cdot 7H_2O$	0.2
Peptone	2.0	Agar	3.0
L-Ascorbic acid*	0.1	Tap water	1,000 ml.
Na_2SO_4	1.5	pH	7.5
$MgSO_4 \cdot 7H_2O$	2.0		

* In order to maintain reducing conditions essential for the initiation of growth of sulfate reducers, the L-ascorbic acid was carefully added to the medium just prior to inoculation.

Chemical analyses: As for mud samples C.O.D., ignition loss, total sulfides and free H_2S were determined. The amounts of sulfates and chlorides in water samples were also determined. For the determination of total sulfides and free H_2S the method reported by Tomiyama and Kanzaki[8] was employed. Sulfates were gravimetrically or nephelometrically determined. C.O.D. and ignition loss of the mud as well as the chlorinity of the water were estimated by the usual methods.

Experimental results: The results of the experiment carried out in 1955 were as shown in Table 1. This table shows that in the river water sulfate-reducing bacteria which could be detected by use of the sea water media were almost evenly distributed in all stations examined with the exceptions of stations 14 and 15. The water samples collected from the stations 6, 7, 8, 9, 10, 11, 12 and 13 contained sulfate-reducing bacteria of the marine type in numbers of from 1 to 10^2 per ml. But at the stations 14 and 15 cells of this organism were never detected in the river water.

Samples of the bottom mud collected from the stations 6, 7, 8, 9 and 10 generally contained these bacteria in larger number than the overlying waters; these mud samples gave counts of 10^4—10^8 cells of marine sulfate-reducing bacteria per one gram. These counts were almost comparable to those found in the mud samples collected from the stations in the coastal areas of Maizuru Bay which contained organic matter in high concentration. In bottom mud samples collected from the stations 11, 12, 13, 14 and 15 the abundance of sulfate-reducing bacteria which could be detected by the sea water media was less than those in mud samples collected from the stations of the lower course of the river. At the station 15 cells of sulfate-reducing bacteria of the marine type were never detected in the bottom mud.

On the other hand, sulfate-reducing bacteria which could grow on the fresh water media were found to be distributed in nearly equal number in the all water samples excepting the sample which was collected from station 6. Station 6 was located in the Maizuru Bay near the mouth of the Takano River, and the water sample from this station did not contain these bacteria at all. At the remaining stations the abundance of these bacteria was found to be 10-10^3 in 1 ml. of the water.

The abundance of sulfate-reducing bacteria of the non-marine type in the bottom mud was 10^4—10^6/g. mud through all the stations examined with the exception of the station 6. The mud sample collected from the station 6 contained sulfate-reducing bacteria of this type in smaller number than the mud samples collected from the remaining stations.

In the mud sample collected from the station 6 less than 10^3 cells of sulfate-reducing bacteria of the non-marine type were contained.

In the bottom mud the total counts of sulfate-reducing bacteria in-

Table 1. Contents of sulfate-reducing bacteria, sulfides, chlorides, and organic

Takano River (June 3 or 8, 1955).

Station number	Distance from the mouth of the river (m.)	Depth of overlying water (m.)	Depth of water collected (m.)	Temperature of water (°C.)	Temperature of mud (°C.)	Chlorinity of water (‰)
6	−100	8.2	0	22.6	18.9	18.02
			7.2	18.1		18.92
7	300	2.9	0	20.8	19.6	15.75
			1.9	20.0		18.26
8	700	0.5	0.3	22.0		2.41
8[1]	700	0.6	0.5	22.9		12.92
9	750	0.7	0	20.0		2.04
			0.6			2.13
9[1]	750	0.8	0.7	21.4		16.54
10	900	0.4	0	20.0		0.04
10[1]	900	0.5	0.4	21.4		0.59
11	1,400	0.2	0	20.4		0.0
12	2,000	0.2	0	20.0		0.0
13	2,400	0.15	0	22.0		0.0
14	1,000	0.45	0	21.5	20.7	0.0
15	2,800	0.2	0	22.2	20.3	0.0

Z. B. : At the stations 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15 water and mud samples

At the stations 8^1, 9^1 and 10^1 water samples were collected at high tide

* Bacteria developing on sea-water media.

** Bacteria developing on fresh-water media.

matter of water and bottom mud samples collected from various stations in the

C. O. D. of mud (O_2 consumed mg./g. dry mud)	C. O. D. of water (O_2 consumed mg./L.)	Loss on ignition (% of dry mud)	Free H_2S content of mud (mg./g. dry mud)	Content of total sulfides (H_2S mg./g. dry mud)	Number of sulfate reducers in 1 cc. or 1 g. of sample	
					Marine formes *	Non-marine formes **
	4.0				$10-10^2$	0
	4.0				$1-10$	0
25.7		12.12	0.294	0.755	10^4-10^5	10^2-10^3
	8.0				$10-10^2$	$10-10^2$
	6.0				$1-10$	0
65.5		14.09	1.572	4.780	10^4-10^5	10^4-10^5
	46.0				10^2-10^3	10^3-10^4
45.4		6.82	0.588	4.575	10^7-10^8	10^6-10^7
	14.4				10^2-10^3	$10-10^2$
	14.0				10^2-10^3	10^2-10^3
85.0		17.60	1.450	6.250	10^6-10^7	10^6-10^7
	10.4				10^2-10^3	0
	32.0				$1-10$	10^3-10^4
77.4		20.50	1.253	1.696	10^6-10^7	10^5-10^6
	56.4					
	65.2				$1-10$	10^3-10^4
140.8		24.81	0.608	1.175	$1-10$	10^6-10^7
	74.0				$1-10$	10^2-10^3
107.4		17.75	0.538	1.972	$1-10$	10^5-10^6
	496.0				$1-10$	10^3-10^4
87.3		35.60	0.502	0.794	10^2-10^3	10^6-10^7
	8.0				0	10^2-10^3
7.9		3.40	0.047	0.082	$1-10$	10^5-10^6
	12.0				0	$10-10^2$
18.7		7.02	0.010	0.210	0	10^4-10^5

were collected at low tide on June 3, 1955.

on June 8, 1955.

cluding both marine types and non-marine types were 10^4—10^7/g. mud through all the stations examined. The total population of these bacteria in the bottom mud was correlated neither with the distance from the mouth of the river nor with the chlorinity of the river water. In general, the abundance of sulfate-reducing bacteria in the bottom mud of these environments was somewhat large than that of the normal coastal areas of the sea.

At the stations 6 and 7 the chlorinity of the water was comparable to that of the open sea even at the low tide. The water samples collected from the stations 8, 9 and 10 were more or less brackish at the low tide as well as at the high tide, but those collected from the stations 11, 12, 13, 14 and 15 were entirely fresh at any time. The chlorinity of the bottom waters from the stations 8 and 9 was more than 12 ‰ at the high tide.

The content of sulfides of the bottom mud was highest at the typically brackish station (station 9), from where the sulfides content of the mud was gradually decreased with the distance downstream as well as upstream. The sulfides content of the mud sample collected from the station 6 was about the same as that of the mud sample collected from the highly polluted station in Maizuru Bay. In the bottom mud of the stations 14 and 15 sulfides were contained in very low concentration.

The organic contents of the mud which were indicated as C.O.D. value were generally higher than those found in the bottom mud of the coastal areas of the sea. Especially, the mud samples collected from the stations located between the draining mouth of the paper factory and the mouth of the Takano River contained organic matter in very high concentration. The highest organic content was found in the mud samples from the stations located closely near to the draining mouth of the paper factory (stations 11, 12 and 13).

Discussion

It is generally thought that the sulfate-reducing bacteria which were freely floating in the water of the river had been incidentally brought there by the turbulence of the water from the bottom mud of the river, the proper inhabiting place of these organisms. Therefore, the distribution of these bacteria in the river water does not seem to be important in discussing the biological or chemical characteristics of the water. The distribution of surfate-reducing bacteria in the bottom mud of the river, however, is very important in discussing the biochemical characteristics of the water, because these microorganisms are generally held to be important agencies controlling the formation of sulfides in the bottom mud. As shown in Table 1, the distribution of the sulfate-reducing bacteria and the sulfides in the bottom mud seemed to be closely related with those of the

C.O.D. value of the bottom mud and the chlorinity of the bottom water. The relationship between these factors were clearly summarized in Figs. 2, 3 and 4.

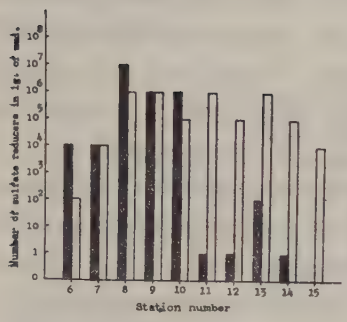

Fig. 2. Number of marine or non-marine sulfate-reducing bacteria in mud samples collected from various stations in the Takano River.
■ : Marine sulfate reducers;
□ : Non-marine sulfate reducers.

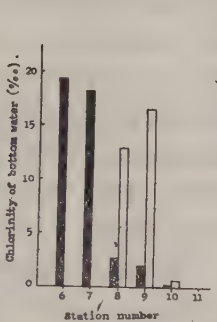

Fig. 3. Chlorinity of bottom water samples collected from various stations in the Takano River.
■ : At low tide;
□ : At high tide.

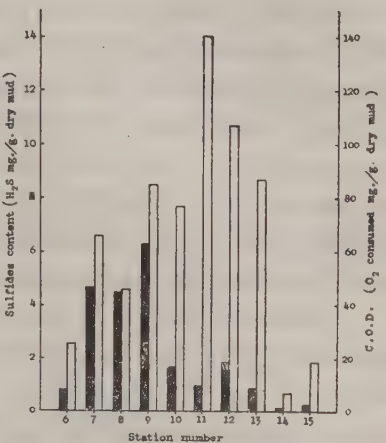

Fig. 4. Relation between sulfides content and C.O.D. of mud samples collected from various stations in the Takano River.
■ : Sulfides content;
□ : C.O.D.

From Figs. 2 and 3, it is found that the abundance of sulfate-reducing bacteria of the marine type in the bottom mud was nearly even in the brackish area between the station 6 and the station 10 where the water was more or less saline. But these bacteria were found to be scanty in the bottom mud of the fresh water area upper than the station 11. The fact that the marine sulfate-reducing bacteria were abundant in the saline or brackish zone where the NaCl concentration of the river water was relatively high is thought to be explained by the salinity requirements of these bacteria, *viz.*, it is generally indispensable for the growth of sulfate-reducing bacteria of this type that the media contain NaCl in the concentration of higher than 1 %, as has been previously reported.[2)]

However, it is also found from Fig. 2 that sulfate-reducing bacteria of the marine type were abundantly distributed in the mud of the station 10 where the river water contained NaCl in the concentration of less than 1 %. This fact may suggest that in the natural environments, not in vitro, the growth of sulfate-reducing bacteria of this type is not limitted by the concentration of NaCl when it is more than about 0.5‰.

The distribution of sulfate-reducing bacteria of the non-marine type of the bottom mud, on the other hand, was something opposed to that of the marine sulfate-reducing bacteria, *viz.*, in the brackish or saline area the abundance of these bacteria generally decreased against the increase of the NaCl concentration of the bottom water. This distribution of sulfate-reducing bacteria of the non-marine type is thought to be due to the low salinity requirement of these microorganisms. As has been reported previously, these bacteria grew exclusively on the media containing NaCl in the very low concentration or free from NaCl. Therefore, the paucity of these bacteria in the bottom mud of the highly saline area appears to be attributable to the high concentration of NaCl in the environment.

However, the Fig. 2 also shows that these bacteria were evenly distributed in the bottom mud in the brackish or fresh water area between the station 8 and the station 13. This fact may suggest that in the natural environments the distribution of these bacteria in the mud is not limitted by the chlorides in the bottom water when its chlorinity is lower than about 2.5 ‰ at the low tide.

Summarizing the distribution of the sulfate-reducing bacteria of both marine type and non-marine type in the bottom mud of the estuarine zone of the river receiving both fresh water and saline water, it may be concluded that in the typical brackish zone (stations 7, 8, 9 and 10) both marine and non-marine sulfate-reducing bacteria were generally distributed in the bottom mud in approximately the same number; in such a zone the distribution of sulfate-reducing bacteria of these two types was not directly influenced by the chlorinity of the bottom water. However, in the purely saline area (station 6) the distribution of sulfate-reducing bacteria of the non-marine type in the bottom mud was highly limitted by the high salinity, and in the purely fresh water area (stations 11, 12, 13, 14 and 15), on the other hand, the distribution of sulfate-reducing bacteria of the marine type was considerably limitted by the low salinity.

The facts that there were a small number of sulfate-reducing bacteria which could be detected by use of the fresh water media in the bottom mud of the purely saline area (station 6), and that there were a few cells of sulfate-reducing bacteria of the marine type in the bottom mud of the purely fresh water area may suggest that in the bottom mud of such areas there were sulfate-reducing bacteria of the euryhaline type which could grow on the sea water media as well as on the fresh water media, in addition to the sulfate-reducing bacteria of the aforementioned two types*.

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* Sulfate-reducing bacteria of these two types resembled to those described in the Bergey's Manual[9] as *Desulfovibrio desulfuricans* (non-marine type) and *Desulfovibrio aestuarii* (marine type).

It is thought that sulfates dissolved in the water in these areas were introduced by the tide from the sea. Therefore, it is expected that the distribution of the salfates in the water was closely correlated with that of the chlorides. The data given in Table 2 were the results of the determination of sulfates and chlorides in the surface and the bottom waters collected from the aforementioned stations in the Takano River. This examination was carried out at the high tide as well as at the low tide on June 4, 1956.

Table 3. Dilution counts for marine sulfate-reducing bacteria in the pure culture.*

Delete

Media employed for the dilution counts			Count (cells/1 cc. of the culture).
Reducing agents contained		Redox-potential just prior to inoculation, (Eh mV.)	
Kind	Concentration (m mol./L.).		
Control (none)	0.0	+323	1–10
L-Ascorbic acid	0.6	+211	10^{8}–10^{9}
〃	6.0	+ 10	10^{8}–10^{9}
L-Cysteine	0.6	+208	10^{8}–19^{9}
〃	6.0	− 13	10^{8}–10^{9}
Na_2S	0.6	+ 81	10^{7}–10^{8}
〃	6.0	−431	10^{8}–10^{9}
Na-Thioglycollate	0.6	+253	10^{4}–10^{5}
〃	6.0	+252	10^{2}–10^{3}

* The pure culture of sulfate-reducing bacteria was counted at 30°C with the media (medium 1[1) 2)] was used as the basal medium) containing various kinds of reducing substances in different concentrations. It was found by the direct microscopic count procedure that the pure culture employed contained 6.2×10^{8} cells per cc.

Table 2 shows that in the saline or the brackish zone (stations 6, 7, 8 and 9*) the concentration of the sulfates in the water was closely correlated with that of the chlorides; the ratio of SO_4^{--}/Cl^{-} of the water samples from these stations was nearly constant and approximately equal to that of the sea water. On the other hand, at the stations located in the upper course of the river (stations 10, 11 and 14) the concentration of the sulfates and that of the chlorides in the water were very much lower than those found in the water samples from the stations located in the lower course of the river (stations 6, 7, 8 and 9), and there was no definite relationship between the concentration of the salfates and that of the chlorides in the water samples collected from the stations 10, 11 and 14.

* On June 4, 1956 the water at the station 10 did not receive sea water even at the high tide at all.

Table 2. Sulfates and chlorides contents of water samples collected from various stations in the Takano River (June 4, 1956).

Station number	At high tide (a.m. 10.00)					At low tide (p.m. 4.30)				
	Depth of sample collected (m.)	Temperature of water (°C.)	SO_4^{--} (g./L.)	Cl^- (g./L.)	$\frac{SO_4^{--}}{Cl^-} \times 100$	Depth of sample collected (m.)	Temperature of water (°C.)	SO_4^{--} (g./L.)	Cl^- (g./L.)	$\frac{SO_4^{--}}{Cl^-} \times 100$
6	0	24.3	1.767	12.85	13.7					
	7.0	17.4	2.631	18.77	14.0	6.0	17.7	2.577	18.59	13.9
7	0	20.8	0.640	4.63	13.8					
	3.5	19.9	2.417	18.18	13.3	2.3	19.4	2.324	18.05	12.9
8	0	21.1	0.139	0.95	14.6	0	26.0	0.044	0.31	14.2
	0.5	21.1	1.716	12.24	14.0	0.4	33.8	1.320	9.06	14.6
9	0		0.059	0.38	15.5	0	27.6	0.067	0.52	12.9
	0.8		1.302	9.12	14.3	0.5	24.6	—	14.63	—
10	0.15		0.0095	0.0162	58.6	0.15	25.3	0.0082	0.0150	54.6
11	0.15		0.0095	0.0195	48.7	0.15		1.0110	0.0155	71.0
14	0.15		0.0058	0.0155	37.4	0.15		0.0053	0.0137	38.6

Based on these data it may be concluded that the sulfates detected in the water samples from the stations 10, 11 and 14 were not originated from the sea.

From Figs. 2, 3 and Table 2 it is also found that in the bottom mud of the stations 11, 12, 13, 14 and 15 where the concentration of sulfates in the water was very low there were a large number of cells of sulfate-reducing bacteria (the greater part of them were of the non-marine type). The total abundance of sulfate-reducing bacteria including both marine type and non-marine type in the bottom mud in these stations was comparable to that found in the bottom mud of the brackish or saline area which contained sulfates in much higher concentration. These facts may suggest that the sulfate-reducing bacteria (especially sulfate-reducing bacteria of the non-marine type) could grow abundantly under the exsistence of sulfates in very low concentration. The relationship between the growth of sulfate-reducing bacteria and the concentration in the media of the hydrogen acceptors for these organisms, such as sulfates, thiosulfates, tetrathionates, and the other compounds, will be reported elsewhere.

From Figs. 2 and 4 which illustrate the relation between the C.O.D. value and the sulfides content or the content of sulfate-reducing bacteria of mud samples collected from various stations it is found that the distribution of total sulfate-reducing bacteria in the mud of these stations was not directly correlated with that of the organic matter expressed as C.O.D. value. The C.O.D. value and the ratio of C.O.D./ignition loss of mud samples collected from these stations were generally higher than those of the mud in the normal coastal area of the sea.[1), 6)] This fact may suggest that in such zones of the river the abundance of sulfate-reducing bacteria in the mud was not limited by the concentration of available organic matter present.

Figs. 2 and 4 also show that the concentration of sulfides in the bottom mud was highest at the station 9, from where the sulfides content of the bottom mud generally decreased with the distance not only upstream, but downstream. Since the sulfides content of the bottom mud in the lower course of the river (stations 6, 7, 8 and 9) appeared to be correlated with the concentration of the organic matter, but not with that of the sulfates, it is thought that the formation of sulfides in the bottom mud of these places was principally controlled by the concentration of available organic matter present.

The concentration of sulfides in the bottom mud in the upper course of the river (stations 9, 10, 11 and 14), on the other hand, seemed to be more directly correlated with the concentration of sulfates than that of the organic matter contained in the mud. It is, therefore, thought that in the

upper course of the river the production of sulfides in the mud was mainly regulated by the concentration of sulfates and not by that of the organic matter present.

These facts may suggest that in the estuarine zone of the river receiving a relatively large amount of organic matter the sulfate-reducing bacteria are almost evenly and abundantly distributed in the bottom mud throughout the length of such a zone, and that the total population of sulfate-reducing bacteria including both marine type and non-marine type in the bottom mud of such an area of the river is not limited by the concentration of sulfates or that of organic matter present, but the formation of sulfides in the bottom and is limited by the concentration of organic matter in the lower course of the river, and by the concentration of sulfates in the upper course of the river.

It is, therefore, expected that the formation of sulfides in the bottom mud is stimulated by the supply of sulfates in the upper course of the river, and by the supply of organic matter in the lower course of the river.

Summary

In order to elucidate the mechanism of the sulfides formation in the estuarine zone of the river receiving industrial and municipal drainages which contain organic matter in high concentration, we observed the distribution of sulfate-reducing bacteria, sulfides, sulfates, chlorinity, organic matter, etc. in the water and in the bottom mud in the Takano River, and subsequently studied the factors which participate in the sulfides formation in such a part of the river. Results obtained are summarized as follows:

1) In the river water relatively small number of sulfate-reducing bacteria were sporadically distributed regardless of the distance from the mouth of the river. The cells of these bacteria detected in the river water seemed to be brought by the water movement from the bottom mud where was the proper inhabiting place of these bacteria.

2) In the bottom mud of the river, the distribution of sulfate-reducing bacteria, in the case of anyone of marine and non-marine types, was more or less influenced by the chlorinity of the bottom water. However, the total counts of the sulfate-reducing bacteria including both types in the mud were hardly influenced by the chlorinity of the bottom water; total sulfate reducers were almost evenly distributed in high count in the bottom mud throughout sea-water zone, brackish zone and fresh-water zone.

3) The distribution of total sulfate-reducing bacteria in the bottom mud was also hardly influenced by organic content of the mud or sulfates content of the bottom water; the growth or the counts of the total sulfate-reducing bacteria in the bottom mud was not limited by organic content

of the mud or sulfate content of the bottom water, *viz.*, in the bottom mud sulfates and organic matter were sufficiently present for the growth of the sulfate-reducing bacteria. It was generally found that organic matter contained in the bottom mud of this region of the river was higher in concentration and more easily decomposable than those contained in the bottom mud of the sea.

4) On the contrary, the formation of sulfides in the bottom mud by the sulfate-reducing batceria was principally influenced by the sulfate content of the bottom water and the concentration of available organic matter in the mud. In the fresh-water zone where the sulfate content of the bottom water was very small, the formation of sulfides in the bottom mud was mainly suppressed by the paucity of sulfates in the bottom water; in the sea-water zone where the concentration of sulfates in the bottom water was very high, the production of sulfides in the mud was primarily controlled by the organic content of the mud; in the brackish zone where both sulfates and available organic matter were sufficiently present, sulfides formed by the sulfate-reducing bacteria were found in very high concentration.

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NOTES ON THE POLYCHAETOUS ANNELID OF KII PENINSULA

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The Japan Society for the Promotion of Science has been intrusted "Fundamental Researches on Oceanic Productivity and Utility" by the Japanese National Commission for UNESCO, and fauna of the polychaetous annelid of Kii Peninsula was investigated in 1956 and 1957 by the author. This report is the result of the survey on the eastern side of the peninsula.

The purpose of the investigation was to estimate the damages caused by the boring polychaeta on pearl shells and oyster in culture, the important marine products in this district.

The investigation was carried out at the following four localities; 1) Toba and the adjacent area, 2) Matoya Bay, 3) Ago Bay, and 4) Owase. Materials was collected from the sea shore, the raft, and the trawl net.

1. Polychaetous Annelids multiplying on the raft of pearl shell and oyster culture

Pearl shell and oyster are usually cultured by the raft. But the growth of the shell is greatly hindered by the epiphyt multiplying in the sediment which attached on the shells. So that the removal of these covering is indespensable work on the process of shell culture. Polychaetous annelids are most remarkably found among these epiphyt and *Polydora, Cirratulus, Syllis* and *Thelepus* are remarkable genera.

Polydora pacifica is a most important species for the shell culture, because this species is oftenly caused a tumour-like growth on inner surface of the shell, and have an influence on growth of pearl. Non-boring polychaeta, also, sticks in the sediment on the surface of the shell. As these polychaeta excretes the mucus by itself and fixes the sediment on the outside of the shells, that it makes the other livings easier to stick.

The following sixteen species of polychaeta are collected.

1. *Iphione muricata* **Savigny** (Toge-urokomushi)
2. Harmothoe *imbricata* **(Linné)** (Madara-urokomushi)
3. *Eularia viridis* **(O. F. Müller)**
4. *Autolytus purpureimaculata* **Okada** (Kakimotoshiris)

5. *Trypanosyllis zebra* **Grube**
6. *Perinereis nuntia* **(Savigny)** var. *brevicirrus* **(Grube)** (Isogokai)
7. *Platynereis dumerilli* **Aud.-Edw.** (Tsuruhige gokai)
8. *Glycera rouxii* **Aud.-Edw.** (Isochirori)
9. *Marphysa sanguinea* **Montagu** (Iwamushi)
10. *Lumbriconereis* **Aud.-Edw.** (Giboshi isome)
11. *Polydora pacifica* **Takahashi**
12. *Cirratulus cirratus* **(O.F. Müller)** (Chigusa mizuhiki
13. *Thelepus setosus* **Quatrefages** (Nippon fusagokai)
14. *Serpula vermicularis* **Linné** (Hitoe kanbashi)
15. *Hydroides* **Gunnerus** (Kasane kanzashi)
16. *Spirorbis* **Moore** (Uzumaki gokai)

2. *Polydora pacifica* which bores holes in *Margaritifera martensi* **Dunker.**

Polychaeta which bores holes in *Margaritifera martensi* **Dunker** in this distriet is *Polydora pacifia* **Takahashi.** This species is widely distributed along the Pacific coast of Japan, and can be easily detected of its existence to recognize the characteristic tumour-like growth on the inner surface of the shell.

This worm generally force its way from the outer margin of the shell and bores hole to the inner surface and advance towards the center. Tumour is formed by the shell itself with this stimulus at this part. As the worm advances little by little making a passage along the pearl layer toward the center of the shell, that the tumour-like growth is lengthend gradually, and the characteristic solid blister is formed. When this growth is quietly removed with a nail and a hammer, two pararell passages are distinctly found at the center and other parts are full of viscous excrement or mud. And the worm moves freely in the passage of the hole. In natural condition, it is seen to put out its two tentacles out of the hole of the shell and move it freely in the water.

(A) General state of damages of the shell

1520 dead *Margaritifera martensi* **Dunker** stored in the Matoya Syster Farm, which are examined with the following result:

Number of shells examined	1520
Number of shells which are bored	183
Number of tumour-like growth	206
Damage percentage	12%

Damage percentage, 12% in this district, is by far less compared with that of 30% of Palao island. It is said that in Palao the mother shell was

infected so much by this worm, the activity of the secretion of pearl was deterioreted noticeably.

(B) Distribution of the growth

Position of the growth on the inner surface of the shell is investigated. The following table shows the distribution of the position of the growth. The distance between the anterior ear and the posterior ear of the shell was divided into five equal parts and names them Area I, II, III, IV, V respectively, counting from the anterior ear. The distance from the anterior ear to the opening of the hole of growth also measured and divided it into each corresponding area.

Area	Number of growth	%
I	26	12.6
II	15	7.3
III	38	18.4
IV	34	16.5
V	78	37.8

It is particularly noticeable that in Matoya, 15 growths which correspond to 7.3% of total number are situated out of forementioned area, and openings of these holes begins from the hinge portion of the shell. It is not so often seen in other places. Generally, the greater number of the growth are observed in Area V than in other areas, and more than a half of all growths are found in Areas V and IV.

3. Benthos polychaeta collected by trawl net

At the mouth of Ise Bay, fishers fish lobster with trawl net at night. Out of these catches in net, polychaeta are collected as follows:

1. *Aphrodita australis* **Baird**
2. *Laetomatonice Japonica* **McIntosh** (Nihon urocomushi)
3. *Chloeia flava* **(Pallas)** (Umikemushi)
4. *Chloeia fusca* **McIntosh**
5. *Nereis ezoensis* **Quatrefages**
6. *Eunice tentaculata* **Izuka** (Ezogokai)
7. *Onuphis conchylega* **Sars** (Konkireisome)
8. *Onuphis willemoesii* **(McIntosh)**
8. *Marphysa sanguinea* **Montagu** (Iwamushi)
10. *Mesochaetopterus Japonicus* **Fujiwara** (Mugiwaramushi)
11. *Asychis disparidentata* **(Moore)** (Takemushi)
12. *Maldanella harai* **(Izuka)**
13. *Amphitrite edwardsi* **(Quatrefages)**
14. Serpula **Linné**
15. *Spirorbis foraminosus* **Moore** (Uzumakigokai)

4. Polychaetous fauna on the eastern side of the Kii Peninsula

Polychaetous annelid collected on the eastern side of the Kii peninsula is the following 44 species belongs to 36 genera. Among them, 18 species are the same as that of Usa, Kochi Prefecture, and 8 species are the same as that of Hachijo Island, both of them investigated by the author in 1955 and 1956. In general, most of the fauna are tropical and sub-tropical species. But northern type also collected as *Arenicola claparedii* **Stimpson**, which is collected from Toshi island located at the mouth of Ise Bay, and it is onsidered as a southern limit of its distribution along the Pacific coast. This worm occurs in great number in a limited area, counting 216 worms in one square meters in several places in this locality. *Perinercis nuntia* var. *brevicirrus* and *Marphysa sanguinea* are collected by fishermen as a bait of fishing in smally way.

Family Aphroditidae

Aphrodita australis **Baird**

Laetomatonice Japonica **McIntosh** (Nihon-urokomushi)

Iphione muricata **Savigny** (Toge-urokomushi)

Harmothoe imbricata **(Linné)** (Madara-urokomushi)

Lepidasthenia Longissima **(Izuka)**

Family Phyllodocidae

Eularia viridis **(O. F. Müller)**

Family Amphinomidae

Chloeia Yava **(Pallas)** (Umikemushi)

Chloeia fusca **McIntosh**

Family Syllidae

Syllis inflata **Marenzeller**

Autolytus purpureimaculata **Okada** (Kakimotoshiris)

Trypanosyllis zebra **Grube**

Family Nereidae

Perinereis nuntia (Sav.) var **(Grube)** (Isogokai)

Perineveis cultrifera **Grube** (Kumadorigokai)

Nereis ezoensis **Izuka** (Ezogokai)

Platynereis dumerilli **Aud.-Edw.** (Tsuruhigegokai)

Family Glyceridae

Glycera rouxii **Aud.-Edw.** (Isochirori)

Family Eunicidae

Eunice tentaculata **Quatrefages**

Eunice aphroditois **(Pallas)** (Ono-isome)

Marphysa sanguinea **Montagu** (Iwamushi)

Diopatra neapolitana **Delle Chiaje** (Sugokai)
Lumbriconereis latreilli **Aud.-Edw.** (Giboshi-isome)
Onuphis conchylega **Sars**
Onuphis willemoesii **(McIntosh)**
Family Spionidae
Polydora pacifica **Takahashi**
Family Chaetopteridae
Chaetopterus variopedatus **(Renier)** (Tsubasagokai)
Mesochaetopterus Japonica **Fujiwara** (Mugiwaramushi)
Mesochaetopterus minuta **Potts**
Family Cirratulidae
Cirratulus cirratus **(O. F. Müller)** (Chigusamizuhiki)
Acrocirrus varidus **Marenzeller** (Kumano-ashitsuki)
Family Chloramidae
Stylarioides eruca **(Claparede)**
Family Capitellidae
Dasybranchus caducus **Grube** (Chirimen-itogokai)
Family Arenicolidae
Arenicola cristata **Stimpson** (Kuromushi)
Arenicola claparedii **Levinsen** (Iso-imomushi)
Family Maldanidae
Asychis disparidentata **(Moore)** (Takamushi)
Asychis Gotoi **(Izuka)** (Gototakefushigokai)
Maldanella harai **(Izuka)**
Family Terebellidae
Thelepus setosus **Quatrefages** (Nipponfusagokai)
Amphitrite edwardsi **(Quatrefages)**
Family Sabellidae
Potamilla leptochaeta **Southern**
Sabellastarte indica **Savigny** (Keyarimushi)
Family Serpulidae
Serpula vermicularis **Linné** (Hitoe-kanzashi)
Hydroides norvegica **Gunnerus** (Kasane-kanzashi)
Spirobranchus giganteus **(Pallas)**
Spirorbis foraminosus **Moore** (Uzumakigokai)

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SHELF SEDIMENTS OF THE GULF OF KUMANO, JAPAN I

Studies of Six Samples off the Central Coast of the Southeastern Kii Peninsula (Preliminary Report)

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Yasukazu Saito
(Department of Oceanography, Tokyo University of Fisheries)

Introduction

Six bottom samples were collected on December 3, 1956 by the Training Ship Shinyo-maru of the Tokyo University of Fisheries at the spots a little onshore side of the outer edge of the continental shelf off the central coast of the southeastern part of the Kii Peninsula.

A Niino type dredge was used for the sampling, and a bathy-thermograph was also used to record the depth-temperature relation in the vicinity of each sampling station. The sediments have been investigated mostly under a microscope. The bottom sampling was done by the junior writer, and the senior one has been engaged in the laboratory research.

The studies have been continued to the present time; consequently, this paper is presented as a preliminary report.

Acknowledgments

The writers are sincerely indebted to Professors Takao Sakamoto of the University of Tokyo and Hiroshi Niino of the Tokyo University of Fisheries for their guidance and assistance, and to Dr. Tetsuro Hanai of the University of Tokyo and Mr. Masuoki Horikoshi of the Yokohama National University for their identification of the organisms.

Also, the writers are indebted to the members of the Shinyo-maru. This research has been partly supported by the Japanese National Commission for UNESCO.

Sampling Locations

The sampling locations are shown in the Figure I, and listed in the

Table I with the water depth at each location. The bathy-thermograph (B-T) observation courses are also added in Figure I.

Table I. Sampling Locations

Station No.	Long. E.	Lat. N.	Depth in Meters	Sampling Date
1	136°12.0′	33°51.2′	191	1956-12-3
2	136°16.2′	33°54.7′	153	〃
3	136°19.8′	33°58.8′	152	〃
4	136°22.0′	34°33.4′	156	〃
5	136°27.2′	34°06.8′	157	〃
6	136°32.4′	34°09.0′	210	〃

Fig. 1. Sampling Locations

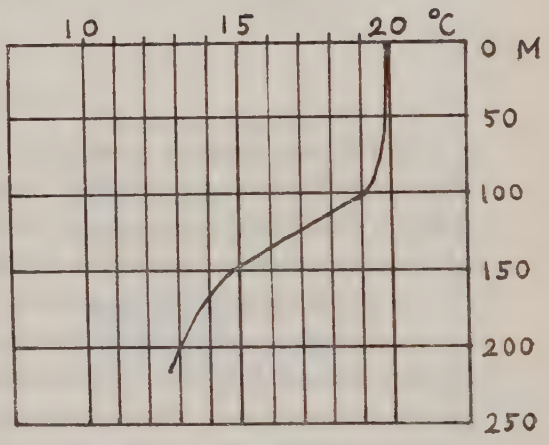

Fig. 2. Depth-Temperature Relation (obtained by B-T) in the vicinity of Station 1.

General Statements

The southeastern coast of the Kii Peninsula runs about 120 kilometers from Kushimoto, southernmost point of the Peninsula, to the Shima showing the SW-NE trend concave to the sea. The Gulf of Kumano faces to this coast.

The southern part of this area shows fairly simple, monotonous coast line, while the central and northern parts present quite complex coast line rich in drawned valleys.

The width of the continental shelf spreads from approximately 5 kilometers at the southern half of the central coast to about 10 kilometers at the northern half. The distance along the central coast is approximately 50 kilometers.

Six bottom samples were collected off the central coast along the line almost parallel and close to the outer edge of the shelf, having 10 kilometers interval between each station. The depth of each sampling spot ranges from 150 to 200 meters.

B-T observations were carried 2 kilometers east of each sampling location mostly, and the resulted temperature-depth relations almost coincide each other. A representative example of the results is illustrated in Fig. 2; the temperature of the surface water is approximately 20°C and decreases slightly to the depth of 90 meters. Then, the thermocline begins and the temperature decreases continuously downward. It is 15°C at the 150 meter deep and 13°C at the 200 meter deep.

Although the B-T observations were carried a little offshore side of each sampling location, where the depth of water exceeds 200 meters, the temperature-depth relation of each sampling location might resemble to that of the near-by B-T station. The B-T results may contribute to the research for the organic constituents of the sediments collected.

A brief statements on the background geology will be added here. An acidic intrusive mass occupies the southern half of the central coast, followed by the Paleogene, partly Neogene, Tertiary formations in the further south. The northern half of the central coast is occupied by the Mesozoic sedimentary formations. The interrelation between the collected sediments and the land rocks will be discussed in the following paper.

Sediments

The collected sediments resemble each other, and show many common features. Shell fragments as well as Foraminifera are abundant, and also light minerals like quartz and feldspar are also dominant.

SIZE: Fractions ranging from 0.1 mm to 0.25 mm are dominant under a microscope except the sediments collected at Stations 2 and 6 where those ranging from 0.2 mm to 0.3 mm show the predominance. Grains of about 1 mm are also involved in the sediments at Station 6. Even though fine sands are dominant, silt-clays are also contained so that these sediments can be called as silty sand in general.

COLOR: Each sample shows greenish blue or bluish green in dry condition.

ROUNDNESS: Mostly the roundness of quartz and feldspar grains are observed; the roundness are bad in general, mostly in a range from 0.1 to 0.4 of the Krumbein's Table (Krumbein, 1941). That of Station 6 is a little exceptional and the upper limit of the range is extended to 0.6.

MINERALS: Quartz, feldspar and calcite (organic calcarious fragments) are dominant; albite is rich in feldspar: orthoclase is also recogniz-

ed. There are abundant dark minerals. Among them, opaque minerals are few in sediments at Stations 1 and 4. It is characteristic to see hypersthene fractions commonly, while mica is much less in the sediments. Foraminifera content at Station 1 is much more than that in every other sample and may be close to 50 % in volume.

Organisms

Shells are abundant both in perfect shape and in pieces. Foraminifera are also very abundant in each sample. Common organisms, but small in amount, are sponge spicules, echinoid fragments, coral fragments, and tubes made by Polychaeta.

Broken pieces of crab or shrimp are recognized at Station 1. A Crinoid, one Alcyonacea, and an Echinoid are also seen in the sample at Station 6. The organisms are listed here as follows.

MOLLUSCA: It is characteristic to have Pteropoda commonly besides benthonic shells.

Station 1 *Bittium* ? sp.
Cavolina longirostris (Blainville)
Machaeroplax nyssona (Dall)
Nipponolimopsis nipponica (Yokoyama)
Olivella sp.

Stations 2 *Cuspidaria* sp.
Dentalium (Laevidentalium) crocinum Dall
Gen. et sp. indet. *(Retusidae)*
Latiaxis sp. (aff. *kawamurai* Kuroda)

Station 3 *Clio pyramidata* Linné
Dentalium (Paradentalium) nivosum Kuroda et Kikuchi
Glycymeris rotunda (Dunker)
Gen. et sp. indet. *(Retusidae)*
Saccella sematensis (Suzuki et Ishizuka)

Station 4 *Cavolina longirostris* (Blainville)
Clio pyramidata Linné
Dentalium (Laevidentalium) crocinum Dall
Glycymeris rotunda (Dunker)
Olivella sp.
Pectunculina oblonga (A. Adams)
Styliola subula (Quoy et Gaimard)

Station 5 *Calyptraea* (s.s.) *yokoyamai* Kuroda
Dentalium (Paradentalium) nivosum Kuroda et Kikuchi
Glycymeris rotunda (Dunker)
Glycymeris vestita (Dunker)

Isanda (Minolia) elegantisculpta Kuroda (MS)
Pectunculina oblonga (A. Adams)
Saccella sematensis (Suzuki et Isizuka) ?

Station 6 *Clio pyramidata* Linné
Trochocerithium sp.

FORAMINIFERA: The detail will be described in the following paper because of their abundance both in numbers and kinds. Planktonic and benthonic Foraminifera are both abundant. *Globigerina bulloides* d'Orbigny, *Globorotalia menardii* (d'Orbigny) and *Globorotalia tsumida*, which indicate warm surface water, are common in the planktonic ones. It well reflects the present circumstance that the water temperature is almost 20°C from the surface to the depth of 90 meters in December.

OSTRACODA: These are fairly common, although the number of each individuals is much less in comparison with those of Mollusca and Foraminifera. Most of the followings will be reported here firstly in Japan.

Station 1 *Bradleya* (?) sp.
Xestoleberis sp.
Station 2 *Bairdia* sp.
Cytherella sp. α
Pterygocytheris sp.
Station 3 *Trachyleberinae* gen. et sp. indet.
Station 4 *Cytherella* sp. ß
Pontocypris (?) sp.

CORAL (ANTHOZOA):

Station 2 *Stephanophyllia formosissima* Moseley
Station 4 *Stephanophyllia formosissima* Moseley
Station 6 *Alcynnacea* ?

POLYHAETA:

Station 2 Gen. et sp. indet. (tube)
Station 3 *Ditrupa* ? sp. (tube)
Station 4 *Ditrupa* ? sp. (tube)
Station 6 Gen. et sp. indet. (tube)

CRINOIDEA:

Station 6 *Perometra diomedeae* (A. H. Clark)

ECHINOIDEA:

Station 6 *Laganum fudsiyama* Döderlein

Summary and Conclusions

Six bottom samples at the spots a little onshore side of the outer edge of the continental shelf are collected off the central coast of the southeastern

Kii Peninsula. Each station has ten kilometers interval approximately and has five to ten kilometers distance from the shore. Four of them are about 150 meters deep, and the rests are close to 200 meters.

The constituents of sediments collected in the above mentioned stations resemble each other, and all of them are silty sand showing the predominance in range of fine sand, 2 ϕ to 3 ϕ in diameters by the ϕ-scale system (Inman, 1952, or Nasu, 1956).

The sediments are partly calcareous organic fractions, and terrigenous materials are also dominant. Angular quartz and feldspar, especially albite are dominant; and hypersthene grains are also common among the dark minerals. Shells in perfect shape and in pieces as well as Foraminifera are abundant. Planktonic Foraminifera indicating warm surface water are abundant.

The bathy-thermograph observation results show 20°C at the surface, 15°C at 150 meters deep and 13°C at 200 meters in depth.

It is quite characteristic to see much less mica fractions; this may be partly due to the action of the coastal currents circulating around the Gulf of Kumano.

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A WEATHERING AND MARINE EROSION PRODUCT OBSERVED ALONG THE COAST OF MIE PREFECTURE, JAPAN

By Kotora Hatai and Hideo Mii
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Introduction

The development of tide-pools, small or large, is a common phenomenon on rocky coasts and they have been studied both from geological and biological sides. Those developed in granite-porphyry along the coast of the outer part of Kuki Bay, in unknown Mesozoic sandstone of the eastern tip of the Shima Peninsula, and in rocks of the same age along the the Pacific coast of Koga Village in the Shima Peninsula, all in Mie Prefecture, as well as those in the early stage of development in Paleozoic impure limestone on the Pacific coast of the Atsumi Peninsula, Aichi Prefecture, have been observed by the writers.

These tide-pools seem worthy of description and form the basis of this article.

Acknowledgements

For cooperation in the field the writers express their gratitude to Messrs. Yoshio Araki and Jun Yamada of the Mie University, and to Miss Tomoko Takeda of the Tohoku University. Particular thanks are due to Mr. Takeye Araya of the National Research Council of Japan for making the arrangements necessary for the field trip.

Tide-pools of Kuki, Mie Prefecture

The tide-pools were found at the outer northern part of Kuki Bay in the southeastern part of Mie Prefecture. These are developed in granite-porphyry, at the intersection of joints which have various trends. By blasting of waves the rocks between the joints are removed to leave depressions, which later become tide-pools.

Numerous joints are developed in the granite-porphyry and may be grouped into three sets with trends of northwest to southeast, north to south, and, northeast-southwest. Although the majority of the joints are vertical or steeply sloping, there are also numerous ones developed at

angles perpendicular to them. Along the joints and by weathering there are developed fissures which are broad at surface but gradually diminish in their width with depth. The surface of the igneous rocks is crumbly owing to weathering and at places exfoliation structures are developed, more commonly and densely arranged where vegetation is heavy and only sporadically where vegetation is almost lacking. The sizes of the formers are smaller than those of the latters. Enlarging of the fissures by weathering is greater at the sea-coast than inland, and wider at or near sea-level than several meters above. At or near sea-level the crevices are occupied with marine plants and animals as those of the Cirripedia, Gastropoda, Pelecypoda and Anthozoa, while several meters above sea-level marine life is lacking.

Above sea-level it was noticed that subground water flowed sparingly in one of the large crevices and is though to have been responsible for its enlargement. Where no water flowed, the crevices of the joints were not so wide and their surfaces were crumbly. It is considered that chemical and mechanical weathering together with the blasting of waves played parts in the gradual enlarging of the crevices and final removal of the jointed rocks.

The joints although more or less vertical in their dips, intersect one another where they are oblique, and where they do not intersect, the horizontally developed joints serve the same purpose for faciliating their removal by wave blasting. Once the blocks of granite-porphyry are removed by wave blasting, they fall into the sea adjacent to the sea-cliff to be transported elsewhere before final depesotion. This seems to be justified by the fact that very few boulders or cobbles of ganite-porphyry could be seen covering the shallow sea-bottom adjacent to or near vicinity of the sea-cliff. As shown in Fig. 6, the tide-pools developed by chemical and mechanical processes in the present case is not of large size nor of any noteworthy depth, and generally their bottoms are rather steeply inclined towards the point of maximum depth.

Once a tide-pool of such nature is developed its further enlargement takes place by mechanical wearing by rocks in its bottom being rotated by wave action. In this sense its further development resembles the construction of pot-holes.

The large boulder occupying the tide-pool shown in Fig. 6 has its surface covered with dead calcareous algae, which in turn has covered some cirripeds and upon which some have later become attached. Whether this boulder was transported by wave action after construction of the tide-pool or actually represents the former tide level is not known.

Tide-pools of Koga, Shima Peninsula, Mie Prefecture

The tide-pools found in sandstone of unknown Mesozoic age developed along the coast of Koga Village on the Pacific side of the Shima Peninsula, develop in a process similar to yet somewhat different from those observed at Kuki, above mentioned.

These tide-pools (Figs. 1, 4, 5) are developed in sandstone which is coarse grained, of brownish color and massive in general. In this massive homogeneous sandstone which has been disturbed by the folding and faulting of the Mesozoic strata, probably intricate structures were developed, but owing to its massive nature the features are obscured. If this is the case, then it can be considered that percolating waters will more easily penetrate the boundary parts of the blocks in the intricately structured sandstone. Conversely the intricate structure of the sandstone will be revealed as a result of subsequent deposition by mineral waters, and the structure of the massive sandstone due to the intense folding and faulting will become apparent.

In Fig. 1 there are shown various stages in the development of the intricate structure of the sandstone and also the incipient development of a tide-pool in the middle part of the photograph. In Figs. 4, 5, fairly well developed tide-pools in the sandstone are shown, and from the sizes, shapes and arrangements of the respective blocks bounded by variously developed cracks, it may be judged that their development may have been the result of or at least greatly effected by differential stress and strain during diastrophism. In this respect, the tide-pools of Koga are considered to have evolved in a process differing from those of Kuki.

However, once penetration into the sandstone of percolating waters is commenced, it seems evident that chemical and mechanical agencies work together for the development and final removal of the various blocks of sandstone. At a glance the sandstone appears to be jointed, but it is considered that this apparent jointing is not correlative with those developing in igneous rocks. After one of the blocks becomes freed or almost freed from its parent rock, blasting by waves seems to be the final force necessary for peeling off the covering rocks. Once peeled, the same process may be repeated.

Once a depression is formed in the way above stated, both chemical and mechanical agencies take par in its enlargement in size and depth.

pool at the eastern tip of Shima Peninsula

The tide-pool to be mentioned hereunder was found in an alternation of massive conglomeratic sandstone and shale of unknown Mesozoic age

widely distribtued in the Shima Peninsula. The development somewhat resembles that of Koga already described except for that instead of the formation of blocks and cracks by penetrating waters, concretion-like structures (Fig. 3) are developed. These concretion-like structures are due to exfoliation, and interesting to notice, is that the external layers of the respective onions are peeled off by mechanical agencies, thereby isolating the ball from its parent rock.

Since the density of these exfoliation structures is rather great and the parent rock much softened by penetrating waters, isolation of the balls are easily accomplished, resulting in enlarging the depression by the first detached ball. By this process it is considered that the tide-pools of the present locality were formed, and in this respect they somewhat resemble the construction of marine pot-holes due to dislodging of the pebbles from the matrix as described by Hatai and Mii (1958, This Journal).

Incipient Tide-pool in Impure Limestone

An incipient tide-pool was found in the Paleozoic limestone developed in a narrow area along the Pacific coast of the Atsumi Peninsula, Aichi Prefecture (Fig. 2). This limestone is impure and coarse crystalline in part, variously deformed by subsequent pressure and incised with variously shaped troughs and depressions. These depressions are mostly developed along the blocky portions of the limestone and where the degree of impurity changes in other parts of the rock. Solution dissolving the interstices of the blocky portions and attacking portions where the lithofacies changes probably opened the path for mechanical action of waves. Although no noteworthy tide-pools were noticed in the said limestone, there are noticed evidences suggesting that time will eventually result in the production of them.

Summary

1. Tide-pools developed in granite-porphyry, impure limestone, and massive coarse grained sandstone were observed along the coasts of Mie and Aichi Prefectures. These are described and illustrated.

2. Development of the tide-pools resemble one another but differ in that their shapes and sizes are related with the characteristics and structures of the rocks in which they occur and by their process in growth.

3. Tide-pools are products formed in the inter-tidal zone and it is thought that some depressions found on unconformity surfaces in geological formations may have had a similar origin.

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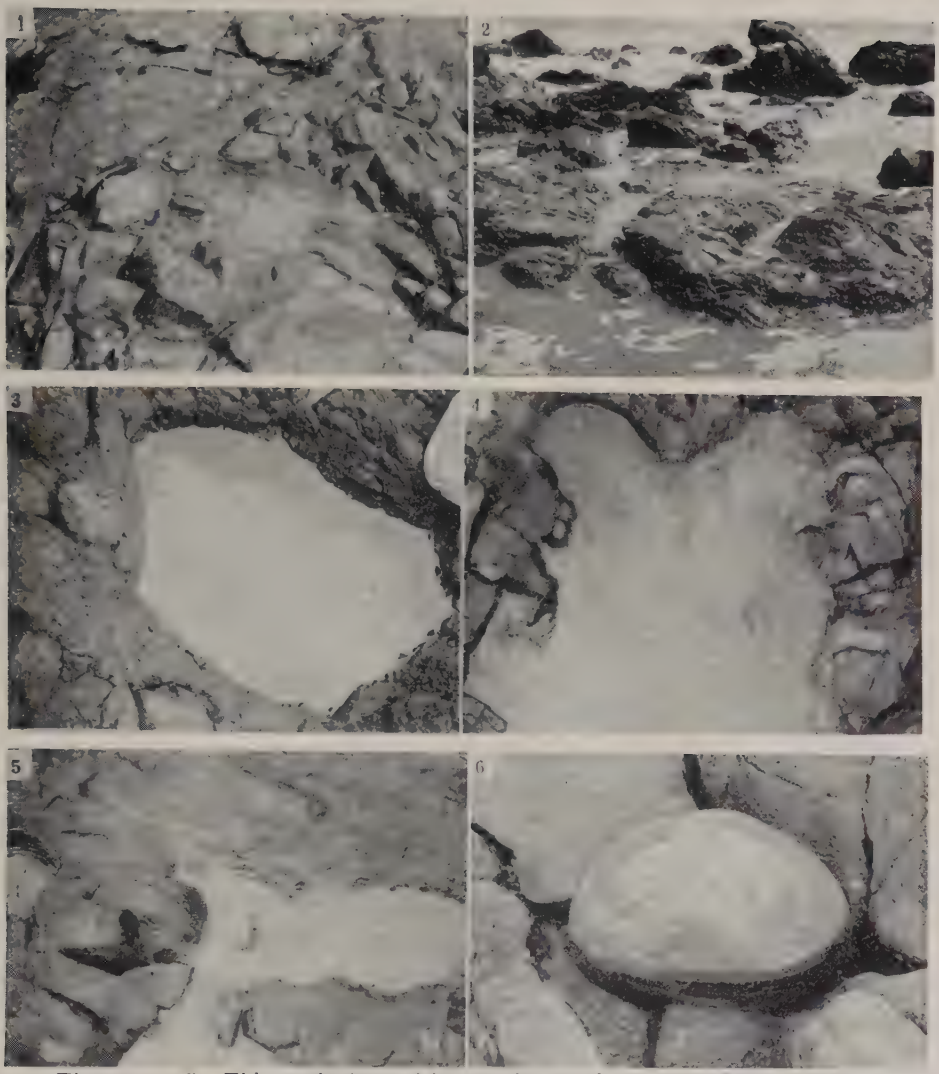
Explanation to Plate



Figs. 1., 4., 5. Tide-pools formed in massive sandstone of unknown Mesozoic age along the coast of Koga, Shima Peninsula, Mie Prefecture. Notice the sizes and shapes of the blocks bounded by cracks giving the impression of joints. Fig. 1 shows an incipient tide-pool. Fig. 5 one is a more advanced stage, and Fig. 4 a well developed one.

Fig. 2. Incipient development of a tide-pool in impure limestone of Paleozoic age along the Pacific coast of the Atsumi Peninsula, Aichi Prefecture. Although solution may play the important role it is also considered that aqueous erosion is also important.

Fig. 3. Tide-pool closely similar to a marine pot-hole developed in onion-structure sandstone of unknown Mesozoic age at the eastern tip of the Shima Peninsula, Mie Prefecture.

Fig. 6. Tide-pool developed in granite-porphyry as a result of chemical and mechanical agencies. The pool is formed in the sea of intersecting joints after the removal of the block by blasting of waves.

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TONGALLEN FROM THE ATSUMI PENINSULA, AICHI PREFECTURE, JAPAN

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Introduction

The formation of Tongallen or clay galls has been described in detail by W. H. Twenhofel (1932), A. W. Grabau (1913), Richter (1926, 1929), and F. Trusheim (1929), and fossil examples of them are recorded by R. Harkness (1856) from Scotland and by W. H. Twenhofel (1932) from the Dresbach sandstone of western Wisconsin. In strata these are said to occur as lenticles of clay or as stem-like structures.

Having had the opportunity to observe from Recent Tongallen in the process of formation on the backshore of the beach of the east coast of the Atsumi Peninsula, Aichi Prefecture, it is considered that their description may be of some value to persons having interest in sedimentary structures.

Acknowledgement

We thank Mr. Takeye Araya of the National Research Council of Japan for the opportunity to make observations on the Tongallen to be described in this article.

Tongallen of the Atsumi Peninsula

Along the foot of the cliffs developed on the east coast of the Atsumi Peninsula there is often found a thin layer of mud spread on the sandy backshore covering an area of about five meters in width and less than ten meters in length. The covering itself measured only about five millimeters to one centimeter in maximum thickness, the underside being slightly impregated or with sand grains glued by the cohesion of the mud, and the upper surface quite free from them except for occasional sand grains scattered by wind transporation. Other features of the mud surface are drag markings due to wind blown plant fragments and small longitudinal grooves or incipient ridges more or less resembling rill-markings formed by the water flowing over it. This kind of mud layer, generally of reddish color, is not rare on the backshore of the beach and have been

observed at several localities, generally at or near the foot of the cliffs.

At most of the localities the mud layer had developed in it irregular cracks in various stages of development and mud cracks so completely developed that the respective flakes by drying curl-up into a variety of forms was found only at one locality.

At this latter locality, there was found many Tongallen in the process of development and its various stages could be observed. These stages are from isolated flakes or detached thin-cakes, those with only the marginal parts curved upwards, to nearly completely formed cylinders of irregular to rather regular shape. These could be easily picked up and rolled on the gently sloping beach without deformation or breaking, which shows that they are quite firm.

From the different stages in development it is clear that first the mud cracks are formed by evaporation, shrinking, then development of cracks which advances to a stage where they cut the layer into numerous flakes or thin-cakes. Then the margins of the respective detached parts curl-up and this curling ultimately results in the production of hollow cylinders of varied lengths and diameters. The longest cylinder observed was about 25 centimeters in length and nearly five centimeters in diameter. From this figure to lower ones there was found numerous examples, mostly of incomplete cylinder form, and all gradations from them to those with only their marginal parts slightly curved upwards.

W. H. Twenhofel (1932) describes that the hollow cylinders may be rolled for "considerable distances and become incorporated in eolian or aqueous sediments". Although he states that the cylinders then flatten to form a thin lenticle of mud as those occurring from the Dresbach sandstones of western Wisconsin, it is also pointed out that they may become filled with sediments without much flattening and thus resemble stem-like structures as reported from the sandstones of Scotland by R. Harkness (1856).

R. Richter (1926, 1929) has shown that Tongallen may develop between tides and even possibly under water, and that they may be transported for some distances as pointed out by F. Trusheim (1929). Thus it is interesting to know that small lenticles in sandstones may be interpreted in this manner and afford datum important for the analysis of the sedimentary environment of a deposit in which they occur. It may also be added that the thin mud blankets with various drag markings or rill-marking like features are also important in interpretation of the conditions under which sedimentation took place.

Although these Tongallen may occur in strata in the state mentioned by W. H. Twenhofel, R. Richter and F. Trusheim or R. Harkness, it may

also be possible that they can occur in other forms. Slight deformation of their original shapes or considerable distortion of them would result in the production of irregularly shaped mud lumps and possibly even small mud balls could develop from them. In this case it is presumed that thin layers or films of sand would be included with simple to complex arrangement, thus serve to or be an aid in studying their origin.

Summary

1. The thin blankets of mud occurring at or near the foot of cliffs of the east coast of the Atsumi Peninsula, Aichi Prefecture, reveal many interesting features as various kinds of drag-and rill-markings, mud cracks and Tongallen.

2. The process in development of the Tongallen was observed and described.

3. The occurrence of Tongallen in sediments is mentioned and their further deformation by distortion is presumed to result in the formation of irregularly shaped mud lumps and possibly even small mud balls.

4. Interpretation of such structures is deemed to be possible from the arrangement of the sand grains included in them.

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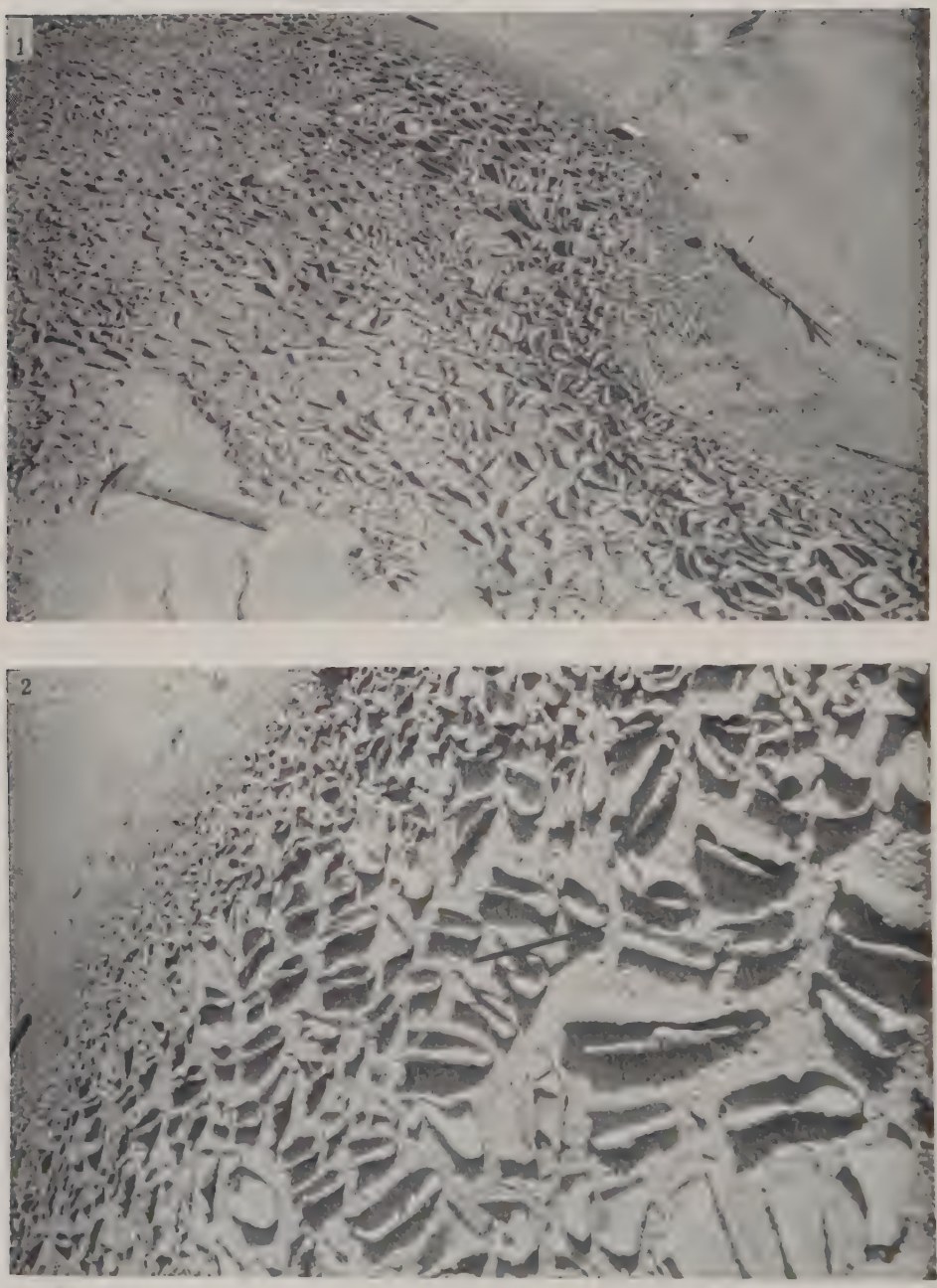
Explanation to Plate



Figs. 1.-2. Mut cracked blanket of mud at foot of cliff on east coast of the Atsumi Peninsula, Aichi Prefecture. Fig. 2 is an enlarged portion of the upper right hand part shown in Fig. 1. The various stages in development leading to the production of Tongallen can be well observed. Tongallen is shown in Fig. 2. These are not yet completely developed.

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AN EROSION FEATURE OBSERVED IN WAKAYAMA AND SHIZUOKA PREFECTURES, JAPAN

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Introduction

In a previous article on the development of certain kinds of marine pot-holes along the coast of Wakayama Prefecture (Hatai, Funayama, and Mii, 1958), it was stated that two types have been described from Japan. One of these types is by Tanabe (1941), who ascribes those in the abrasion platform of Enoshima near Kamakura, Kanagawa Prefecture, to be due to plucking and solution. That is to say, the breaking of columnar joints by wave action and the broken material acting as a grinder assisted with solution resulted in the development of the pot-holes. This is a particular type of marine pot-hole. The other type was newly described by Hatai, Funayama and Mii (1958), who called it a concretion-hole to distinguish it from those types commonly found in stream beds. Their type is described in detail and may briefly be said to be due to solution working in and around concretions embedded in sandstone forming a small abrasion platform, assisted with the mechanical work of waves and currents utilizing the isolated concretion as the grinder. The concretion is dislodged by solution then the concretion as the grinder is rotated by wave action, thereby enlarging the hole and decreasing the diameter of the concretion. Another type of marine pot-hole from the viewpoint of process in development by Hatai and Mii (1958), from their studies along the southern tip of the Izu Peninsula, Shizuoka Prefecture. This type seems to be worthy of special treatment and forms the purpose of this article.

Acknowledgements

For the opportunity to study the various kinds of marine pot-holes, we wish to express our thanks to Mr. Takeye Araya of the National Research Council of Japan for making the necessary arrangement for field work.

Marine Pot-holes formed by Blasting

An interesting type of marine pot-hole was found at the foot of a well-developed notch between Minato and Toji in Asahi-mura on the south coast of Izu Peninsula, Shizuoka Prefecture. This pot-hole is nearly circular in outline, measuring about 1.5 meters in length and width and about 70 centimeters in depth. The sides are quite vertical or very slightly convex, abruptly curve into the rather flat or bowlshaped bottom. The sides seem to be smoother than the bottom and are contrasting with the very rough walls above it. In the bottom of the hole was found sand, granules, pebbles and several boulders of which only one was well rounded, the others had angular sides more or less smoothed by subsequent wear. These materials were probably thrown into the hole by wave action or were directly, in part, derived from the agglomerate cliff into which the notch and pot-hole are incised.

The notch and pot-hole are incised in andesitic cobble to boulder agglomerate tuff. In the cove where the notch and pot-hole occur there are found numerous well rounded cobbles and boulders of andesite lying directly upon the bed rock of andesite agglomerate tuff. These were most probably derived from and by the retarding of the cliff. This large pot-hole seems to have been made partly by the assistance of several andesite rocks rather than by a single one, and the pebbles now found in it may be remnants of larger ones which helped in abrading the bed rock simultaneously with the development of the notch itself. It is considered that the development of the notch and pot-hole were simultaneous, wave action taking place in the former and the derived materials being utilized in the abrading in the latter.

Repeated wetting and drying of the matrix, impregation of moisture between the grains, the action of solution, resulting in the softening or loosening of the grains, leads to dislodging of the cobbles and boulders of andesite from the matrix greatly assisted by the blasting of waves and by removal of the surrounding sediments by both subaerial and subaqueous agencies. Probably thermal agencies may have also played a role during the process of development of both notch and pot-hole.

Once a cobble or boulder is removed from some part of the cliff at or near sea-level, the aforementioned process progresses and the notch and pot-hole are gradually developed. The materials from the cliff serve as grinder in enlarging the incipient depression and in the crushing of smaller materials which thus facilitates the removal of them by wave, current and other agencies.

This same kind of pot-hole was also observed at the base of a notch

developed at the foot of a cliff under an arch near the Seto Marine Biological Station of the Kyoto University in Shirahama-machi, Nishi-Muro-gun, Wakayama Prefecture. Here the notch and pot-hole are developed in a cliff built of conglomerate, which comprises granule to small cobbles of rocks derived from the Paleozoic and Mesozoic Systems developed in the Prefecture. These are well rounded and consist of such as sandstone, shale and slate with minor amounts of other pre-Tertiary rocks. The pot-hole measures about 90 centimeters in longer and nearly 40 centimeters in shorter diameters and is about 40 centimeters in depth. It is now half filled with pebbles brought-in by waves from the adjacent beach.

As in the case of the pot-hole observed in Izu Peninsula, the present one reveals the same characteristic features and is thought to have been formed in the same way. The sides are smoother than the walls above the pot-hole, rather vertical, sharply grade into flat-bottom which is not as smooth as the abraded sides, and occupy a position at the foot of the notch developed under an arch also consisting of conglomerate. Owing to the greater density of the pebbles found in the conglomerate compared with those in the agglomerate tuff of Izu Peninsula, it seems natural that the smoothness of the pot-hole sides are different. However, their process in development is judged to be similar if not actually the same.

That blasting by sea waves under normal condition or during typhoons is of importance can be recognized from other erosion features developed in the cliffs of both Wakayama and Shizuoka Prefectures. The development of notches or shallow to deep irregularities at different heights and in different degrees of development all point to that blasting power of waves cannot be neglected. Also it may be added that the blasting power of winds is similarly important. Weathering processes may be initial but erosion by wind or wave action seems to be the greater factor in the ultimate removal of the pebbles, cobbles or boulders from the matrix and from their place of fall. Although case-hardening helps preserve the cliffs, the above stated phenomena progresses once started, in removing materials by which the different irregularities may be produced.

Summary

From observations on certain kinds of marine pot-holes developed at the foot of notches in the cliffs of southern Izu Peninsula, Shizuoka Prefecture and the cliffs facing the west coast of Wakayama Prefecture, as well as from the erosion features displayed in those mentioned cliffs of two remote places, it is considered that weathering processes may be intial to their development, but wherever an intial depression or irregularity is made, erosion is thought to play the master role. Of the erosion agencies that by

blasting due to waves and also winds is important in the removal of pebbles, cobbles, or boulders from the matrix and from their places of fall. Although case-hardening helps preserve the cliffs, the weathering and erosion forces described in this article, continue removing material therefrom by which irregularities in different stages of development may be produced and further advanced.

Explanation to Plate

Fig. 1. Marine pot-hole formed by dislodging of the pebbles by weathering and blasting. Sea cliff near the Seto Marine Biological Station, Shirahama-machi, Nishi-Muro-gun, Wakayama Prefecture.

Fig. 2. Marine pot-hole at foot of notch, thought to have been formed by dislodging of cobbles and boulders from the matrix by weathering as the initial force and by blasting as the major one. Sea cliff between Minato and Tōji, Asahi-mura, southern tip of the Izu Peninsula, Shizuoka Prefecture.

Figs. 3., 4. Various irregularities formed in the sea cliff near the Seto Marine Biological Station, Nishi-Muro-gun, Wakayama Prefecture. Weathering and erosion forces resulted in their production.

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STRONTIUM AND CALCIUM DISTRIBUTION IN WESTERN PACIFIC, INDIAN AND ANTARCTIC OCEANS

By Ken Sugawara and Nobuko Kawasaki

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Introduction

The widely accepted value of the strontium content in sea water 13 mg/kg, was corrected to be from 7 to 8 mg/kg in 1955 when T. J. Chow and T. G. Thompson as well as K. Sugawara and N. Kawasaki applied new analytical methods to sea water.[1) 2) 3)]

The reason of this revision of the strontium value in sea water is that by the old method of determination, strontium was precipitated as oxalate with calcium and the later separation of strontium from this calcium appears to have been incomplete, giving apparent great strontium values.

Following is a summary of the results of observations on this element as well as calcium which were conducted in the Western Pacific and parts of the Indian and Antarctic Oceans.

Experimentals

Analytical procedure

During storage, parts of the dissolved constituents of collected samples separate to adhere to the container wall. To avoid the error caused by this separation, previous to analysis, the supernatant water is transferred to another vessel and the empty bottle is washed with a warm concentrated hydrochloric acid of a 1% volume of the original water. The washings are united with the transferred sample.

Then the whole is adjusted so that it is approximately 0.1 N for hydrochloric acid, an appropriate acidity with which separation of calcium and strontium starts.

After the addition of 10 ml of a saturated ammonium oxalate solution, 5 g urea and two drops of a methylred solution, 25 ml of the sample water are warmed on an electric plate whereby a homogeneous precipitation of both calcium oxalate and strontium oxalate is ensured. Then the obtained precipitate is processed as indicated in Paper (3).

Experimental error

The reliability of the observed values was checked in three different ways:

1) Analysis of the same sample was repeated with the result in Table 1. The maximum deviation of individual values from the averages is 0.1 mg/l for strontium and 2 mg/l for calcium. The average deviation is 0.07 mg/l for strontium and 0.9 mg/l for calcium.

2) To a number of samples of the same water, an amount of strontium or calcium was added and then analysed. Table 2 shows that the maximum deviation is ± 0.2 mg/l for strontium and ± 3 mg/l for calcium, while the average deviation was −0.15 and +0.17 mg/l for strontium and −1.8 and +2.5 mg/l for calcium.

Results of these two different ways of checking indicate that the maximum error in the observed values is possibly ±0.2 mg/l and consequently ± 0.002 mg-at/l for strontium, and ± 3 mg/l and consequently ± 0.08 mg-at/l for calcium. However, as seen from the subsequent table, in most cases the observed values are more accurate than as expected from these maximum deviations.

3) In the analytical procedure above mentioned, special care was taken to avoid any error which might be caused by separation of precipitate while samples are in storage. The following check proved that such a separation of solids causes no significant error in the obtained result. In order to check this error, the writers used the samples collected at Satuma Station No. 31. The supernatant waters and joint samples of the supernatant and acid washings were compared for strontium content. The results shown in Table 3 indicate that during the course of storage an amount of strontium less than 0.1 mg/l becomes separated.

Results and discussions

The results of observation are listed in Table 6, in which the values for strontium and calcium are expressed in two different forms, values as actually observed and values recalculated in reference to the standard chlorinity. Also the ratio Sr/Ca is added. Discussions are given on the recalculated values.

Surface waters of the Pacific Ocean (see Figs. 1–2)

In these surface waters, strontium varies from 0.078 to 0.112 mg-at/l with an average 0.092 mg-at/l, while calcium varies from 9.7 to 10.8 mg-at/l with an average 10.1 mg-at/l. Then the maximum fluctuation percentage around the average is greater for strontium (+22% and −15%) than for calcium (+6% and −3.6%). However, it is also notable that the decrease in absolute concentration is far greater for

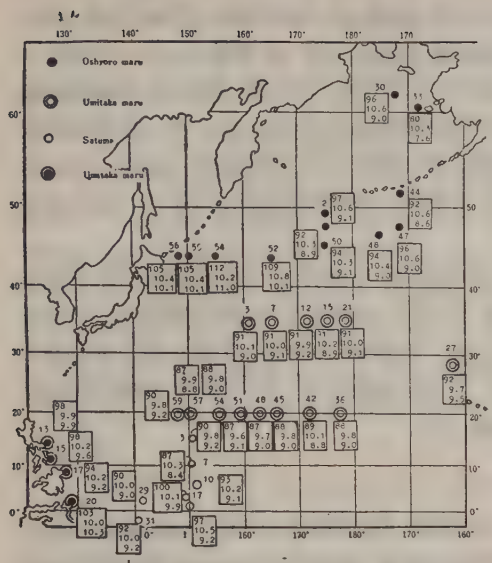

Fig. 1. Surface distribution of strontium and calcium in the Western Pacific Ocean.

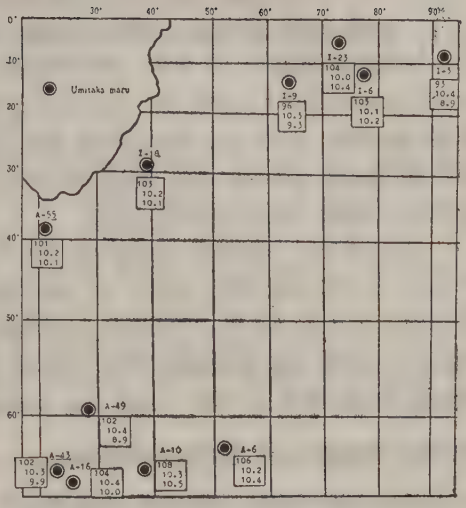

Fig. 2. Surface distribution of strontium and calcium in the Indian and Antarctic Oceans.

Numerals in the squares in Figs. 1-2 are values for strontium mg-at/l multiplied by 1000, calcium mg-at/1, both in reference to the standard chlorinity and the ratio $Sr/Ca \times 10^3$.

calcium (1.1 mg-at/l) than for strontium (0.034 mg-at/l), a relation reflecting on the ratio Sr/Ca so that the ratio tends to decrease with decrease in both strontium and calcium.

With respect to these points, the Northern Pacific waters are divided into two groups. The first group of four stations lying south of the Aleutian Islands from Hokkaido up to E. 165°38.6' is characterised by high values for strontium and calcium, with 0.112 mg-at Sr/l at Station Os. 54, the highest strontium value ever obtained. The second group includes stations east of St. Os, 52 and is characterized by similarly high calcium values and lower, but yet considerably higher, strontium values. One exception is St. Os. 33 where the strontium value, 0.080 mg-at/l, is the lowest ever obtained.

Summarizing the results, the Northern Pacific is characterized by high calcium values and the highest and the lowest strontium values.

Stations along 35°N parallel are rather uniform for both strontium and calcium. In comparison with the Pacific averages, strontium is slightly lower (0.091-0.093 mg-at/l), while calcium fluctuates around the average (9.9-10.2 mg-at/l).

Stations along 20°N parallel are characterized by uniform and low

values of strontium (0.087-0.090 mg-at/l) and of calcium (9.6-10.1 mg-at/1) with low Sr/Ca×1000 which ranges from 8.8 to 9.2.
the increase again of both strontium and calcium, values finally reaching 0.100 mg-at Sr/l at St. Sa. 17, and 10.5 mg-at Ca/l at St. Sa, 16. However, it is notable that the Southern Sea area is rather capricious with values low at some points and high at other points accompanied by a variable Sr/Ca×1000 value (8.5—10.0)

Along the eastern coast of the Philippine Islands, strontium is high, 0.094—0.103 mg-at/l, with an average 0.099 mg-at/l, and calcium value fluctuates around the Pacific average, the values being from 9.9 to 10.2 mg-at/l with an average 10.0 mg-at/l. The value of Sr/Ca is also large, being from 9.2 to 10.1 with an average 9.7.

Indian Ocean and Antarctic Seas

For the Indian Ocean strontium is from 0.093 to 0.104 mg-at/l with an average 0.099 mg-at/l, calcium from 10.1 to 10.4 mg-at/l with an average 10.2 mg-at/l, and Sa/Ca from 8.9 to 10.4 with an average 9.7. Therefore, this ocean is characterized by high values for strontium, calcium and Sr/Ca.

From the Cape of Good Hope south, both strontium and calcium increase. Strontium varies from 0.101 to 0.108 mg-at/l with an average 0.104 mg-at/l, while calcium varies from 10.2 to 10.4 mg-at/l with an average 10.3 mg-at/l. Consequently Sr/Ca is from 9.9 to 10.5 with an ayerage 10.1. The conclusion is that the Antarctic waters are considerably high in strontium, calcium and Sr/Ca.

Vertical distribution of strontium

The vertical distribution of strontium was also surveyed at a number of stations. However, the data are not yet sufficient to permit us to surmise any regularity. The only facts of which we are sure at the moment are: (1) The correlation between strontium and calcium as established for surface water is generally true when waters are compared which are from different depths and are different in the contents of strontium and calcium. (2) Sometimes the difference in strontium content can be available for discriminating waters belonging to different water systems, a discrimination which can not be made otherwise.

Factors causing uneven distribution of strontium in the sea

Unequal distribution of strontium in the sea is evident. The questions are "What is the main factor or factors causing it?" and "How does this uneven distribution occur?" At the moment no clear answer can be given to these questions. For furthering the investigation, how-

ever, it is not useless to consider and discuss the possible factors, i.e., (1) discharge of land waters into the sea, (2) formation of calcareous shells or deposits in the sea and (3) selective escape of strontium from the sea into the air.

Discharge of land waters into the sea.

According to the present writers' investigations in Japan, lake and river waters contain 0.013-0.72 mg/l of strontium, 2.1-18 mg/l of calcium and 0.5-9.9 mg/l of chlorine. Their averages are 0.21 mg Sr/l, 7.5 mg Ca/l and 3.68 mg Cl/l with 0.04, 3.6 and 0.012 respectively for Sr/Cl, Ca/Cl and Sr/Ca. Among these ratios, both Sr/Cl and Ca/Cl are exceedingly high and Sr/Ca is slightly high in comparison with the corresponding sea values, 0.00034 for Sr/Cl, 0.038 for Ca/Cl and 0.0092 for Sr/Ca.

Now, let us imagine that after such land waters flow into the sea, evaporation occurs to that extent at which the chloride concentration equals the ordinary sea value. Then the concentrations of strontium and calcium will be very high, leading to a high content of both these elements in a resulting mixture of these land waters and sea water.

Formation of calcareous shells and deposits

Various kinds of marine organisms take up calcium from the surrounding medium to form calcareous shells. It is also our experience that calcium carbonate is deposited inside a bottle in which a sample of sea water is kept, a deposition which seemingly occurs in a purely inorganic way through escape of carbon dioxide. During these processes, part of strontium in sea water may possibly be entrapped in the calcareous shells and deposits, resulting in decrease of both calcium and strontium in the original sea water. Actually, T. J. Chow and T. G. Thompson determined strontium in a variety of shells of marine organisms with the result that the ratio Sr/Ca was found to vary from 0.001+0.011, an extreme value. The present writers analysed suspended matter which was separated by filtering sea water samples with the results listed in Table 4.

Important is the fact that the ratio Sr/Ca in both calcareous shells and deposits is smaller than for the corresponding sea value, 0.0092, a fact indicating that the formation of calcareous shells and deposits in the sea may result in decrease of calcium and strontium with increase of Sr/Ca value in the remaining sea water. This apparently contradicts our observation detailed above, which firmly establishes that Sr/Ca tends to decrease with strontium and calcium. Then the conclusion is that even if the formation of calcareous shells and deposits be acceptable as

a factor causing decrease in the contents of calcium and strontium in sea water, we must seek for another factor which will bring about decrease in strontium and calcium with simultaneous decrease in Sr/Ca. As such, the writer can mention the escape of strontium from the sea into the air preferentially to calcium and chloride.

Preferential escape of strontium from the sea into the air.

The idea originated in the writers' findings on the distribution of several elements in air and rain, by which they established that calcium and especially strontium are greatly concentrated relative to chloride as compared with the sea. Thus, the ratios Sr/Cl and Sr/Ca in rain are respectively from 0.00081 to 0.0257 and from 0.02 to 0.23 against the corresponding sea values, 0.00034 and 0.0092.

When we consider that the sea represents the primary source of these elements in the air, we must automatically assume that the sea supplies strontium preferentially to calcium and chloride. Then, by losing these elements in this way, sea water is likely to tend to a composition in which calcium is low and strontium lower relative to chloride, with a low Sr/Ca as observed above.

The question is: "In what way does this preferential supply of strontium to calcium and especially to chloride from the sea occur? Two different ways are thinkable.

In the first possible way, the writers assume that at the very moment when a small droplet is formed through collapse of a bubble of sea foam and is emitted into the air, the salt composition of the spray droplet is already different from that of the main sea water so that the spray is enriched by calcium and strontium relative to chloride. The writers term this process the "syn-bubble-breaking-fractionation". Such a possibility is not unacceptable when we imagine a very thin film of sea water at the sea surface where there is an unequal distribution of elements between the film and that main water owing to surface action.

Really, following experiment appears to favor such a possibility. Air is forced to bubble through a sample of sea water placed in a bottle and a connected tubes with distilled water are arranged to collect the emitted spray to be determined for sodium and chloride. As shown in Table 5, the analysis result indicates that the spray is laden with chloride preferentially to sodium.*

The question is whether or not there is preferential enrichment of

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* Through private communitation from Y. Miyake the writers learned that he and I. Sugiura attempted a similar experiment.

spray by calcium to chloride and by strontium to calcium? Experiments are now underway. The writers expect they can report on the result soon.

The second possible way for fractionation is termed by the writers the "post-wave-breaking-fractionation."**

After spray is emitted into the air, evaporation causes separation from the suspended droplet of the least soluble components as salt crystal. Then the crystal chances to split away from the original spray droplet. As evaporation proceeds, other kinds of salts will successively separate and split, leaving a droplet enriched by salts more soluble.

Thus, it is possible that one original spray droplet can separate into a number of entities which differ from one to another in nature and in size. The entities are not necessarily of a pure salt but may be a mixture of salts in which, for instance, sometimes potassium chloride and at other times strontium carbonate predominates. Some entities may be non-hygroscopic and others may be liquid or semi-solid. These differences in chemical as well as physical natures may cause differences in the stability by which the several entities can remain in the air. Consequently, while entities with greater stability remain longer in the air, those with a smaller stability tend to fall back into the sea earlier to replenish the once decreased stock. Really, there are good reasons to suppose that in this post-wave-breaking-fractionation, calcium and particularly strontium represent stable components, while chlorine is the least stable. Then the balance of the sea for these elements through this type of fractionation is nothing but the preferential loss in strontium relative to calcium and particularly to chloride.

As described above, the two proposed ways for preferential escape of strontium from the sea stand on absolutely different bases. Therefore, they can not be expected to always work for an element in the same direction; at times they work for some element in opposite directions. Really, as proved in the previous experiment, the syn-bubble-breaking-fractionation is active in the preferential supply of chloride to sodium into the air, while the post-wave-breaking-fractionation favors a preferential decrease of chloride to sodium in the air. This difference may be available for deciding between the syn-bubble-breaking-fractionation and the post-wave-breaking-fractionation as to which is more effective in determining the final loss of several elements from the surface of the sea.

** Part of Sugawara's idea of the fractionation of the components of atmospheric salt has been published in the Bulletin of the Chemical Society of Japan[4)5)] and a comprehensive description of his theory of fractionations of syn-bubble-breaking and post-wave-breaking will be published elsewhere in the near future.

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Table 1

(a)

Location	Depth m	Sr observed mg/l		Deviation from the average mg/l
St. Os. 1	0	7.6	7.8	0.1
St. Os. 2	0	8.1	8.2	0.05
St. Os. 2	24	8.2	8.2	0.0
St. Um. 12	0	8.6	8.8	0.1
St. Um. I—18	0	9.2	9.1	0.05
St. Um. I—23	0	9.2	9.0	0.1
St. Um. A—16	0	8.8	8.8	0.0
St. Um. A—43	0	8.8	8.0	0.05

(b)

		Ca observed mg/l		Deviation from the average mg/l
St. Os. 1	346	410	410	0
St. Os. 1	1335	402	406	2
St. Os. 48	1462	417	416	0.5
St. Um. 13	0	396	398	1.0
St. Um. I—18	0	420	423	1.5
St. Um. I—23	0	404	404	0
St. Um. A—16	0	420	423	1.5

Table 2

(a)

Location	Depth m	Sr original mg/l	Sr added mg/l	Sr found mg/l	Deviation forn calculated values
St. Sy. 1	0	7.0	4.0	10.9	−0.1
St. Sy. 1	10	6.8	4.0	11.0	+0.2
St. Sy. 1	500	8.0	4.0	12.0	0.0
St. Sy. 2	0	8.0	2.0	9.9	−0.1
St. Sy. 2	0	8.0	4.0	12.1	+0.1
St. Um. I—18	0	9.2	2.0	11.0	−0.2
St. Um. I—23	0	9.2	2.0	11.0	−0.2
St. Um. A—43	0	8.8	2.0	11.0	+0.2

(b)

		Ca original mg/l	Ca added mg/l	Ca found mg/l	Deviation from calculated values
St. Os. 1	346	410	20	427	−3
St. Os. 1	1335	402	20	420	+2
St. Os. 48	1462	417	20	436	−1
St. Um. 13	0	396	20	413	−3
St. Um. I—18	0	420	20	442	−2
St. Um. I—23	0	404	20	423	−1
St. Um. A—16	0	400	20	423	+3
St. Um. A—43	0	405	20	436	−1

Table 3

Location	Depth	Sr mg/l	
	m	Supernatant water	United solution
St. Sa. 31	0	8.1	8.2
St. Sa. 31	100	8.8	8.9
St. Sa. 31	219	8.2	8.2
St. Sa. 31	318	8.0	8.1
St. Sa. 31	419	8.1	8.2
St. Sa. 31	516	8.5	8.6

Table 4

Sr/Ca for suspended matter in sea water and for marine shells

Location	Depth	Sr mg/l		Sr/Ca
	m	Filtered sea water	Suspended matter	Suspended matter
St. Sy. 1	0	7.0	0.1	0.0024
St. Sy. 1	100	8.7	0.1	0.0010
St. Sy. 1	200	7.4	0.1	0.0007
St. Sy. 1	400	8.4	0.2	0.0026
St. Sy. 1	500	8.0	0.1	0.0011
St. Sy. 1	600	8.8	0.1	0.0045
St. Sy. 2	0	8.0	0.1	0.0011
St. Sy. 3	0	7.4	0.2	0.0010
T. J. Chow and T. G. Thompson's data for marine shells. 0.0010—0.011 (0.003)				
Sea water				0.0092

Table 5

Comparison of Na/Cl between sea water and sea spray collected in distilled water

Spray sample	Na mg/l	Cl mg/l	Na/Cl
1	2.5	8.4	0.44
2	1.5	3.96	0.48
3	12.0	27.4	0.67
Sea water			0.86

Table 6.

Oceanographical Observation by "Oshoro-Maru". July 21 - Aug. 24, 1956

Depth	Temp.	Cl	pH	O_2	Silicate	Phosphate	recalculated based upon Cl 19‰				
					Si	P	Ca	Sr	Ca	Sr	Sr/Ca
m	°C	‰		cc/L	μg-at	μg-at	mg-at	mg-at	mg-at	mg-at	
Station 1. Date: July 21 Time: 0300-0700 Lat.: N 48°00′ Long.: E 175°00′											
0	10.2	18.05	8.2	6.80	42.4	0.93	9.8	0.087	10.3	0.098	0.0089
9	9.53	18.05	8.3	—	31.8	0.98	9.9	0.072	10.4	0.077	0.0073
22	7.41	18.16	8.25	7.56	35.9	0.93	9.8	0.072	10.2	0.076	0.0074
45	5.26	18.28	8.25	7.21	43.8	1.21	9.6	0.071	10.0	0.075	0.0074
70	4.76	18.28	8.3	7.68	41.8	1.21	10.0	0.080	10.4	0.084	0.0080
90	4.27	18.29	8.2	7.03	40.9	1.35	10.0	0.080	10.4	0.084	0.0080
139	3.48	18.60	8.0	4.58	51.1	1.36	10.1	0.091	10.3	0.093	0.0090
163	3.30	18.68	7.9	2.63	64.1	1.88	10.3	0.097	10.5	0.092	0.0094
236	3.41	18.80	7.7	1.19	75.3	—	10.2	0.081	10.3	0.082	0.0079
346	3.44	18.86	7.6	0.96	86.4	2.51	10.3	0.078	10.4	0.079	0.0076
420	—	18.90	7.6	0.65	91.9	2.58	10.2	0.094	10.3	0.075	0.0092
497	3.37	18.95	7.65	0.55	92.5	2.68	10.2	0.088	10.2	0.088	0.0086
670	3.02	18.97	7.7	0.56	100.0	2.74	10.3	0.088	10.3	0.088	0.0085
851	2.74	19.03	7.7	0.51	111.	2.31	10.3	0.088	10.3	0.088	0.0085
1040	2.67	19.05	7.8	0.74	105	2.42	10.0	0.087	10.0	0.087	0.0087
1335	2.32	19.09	7.7	0.86	117	2.37	10.0	0.087	10.0	0.087	0.0087
Station 2. Date: July 21 Time: 1900 Lat.: N 49°30′ Long.: E 175°00′											
0	8.7	18.08	8.15	7.47		1.41	10.1	0.092	10.6	0.097	0.0091
10	8.46	18.14	8.2	7.03		1.31	9.8	0.096	10.2	0.100	0.0097
24	7.07	18.16	8.1	7.25		1.14	9.9	0.094	10.3	0.097	0.0095
49	4.79	18.26	8.0	7.00		1.38	9.8	0.082	10.2	0.086	0.0084
73	3.68	18.28	8.0	6.97		1.72	9.9	0.092	10.3	0.096	0.0093
90	3.62	18.36	7.9	6.55		2.12	10.0	0.091	10.3	0.094	0.0091
135	3.61	18.68	7.8	2.58		2.79	10.1	0.092	10.3	0.094	0.0091
180	3.59	18.78	7.8	1.59		3.04	10.1	0.090	10.2	0.091	0.0090
205	3.58	18.79	7.8	1.63		3.29	10.1	0.100	10.2	0.101	0.0099
259	3.70	18.87	7.7	1.33		3.14	10.0	0.095	10 1	0.096	0.0095
327	3.51	18.90	7.75	0.68		3.34	10.3	0.100	10.4	0.101	0.0097
395	3.45	18.91	7.7	0.65		3.34	10.3	0.087	10.4	0.088	0.0088
534	3.30	18.98	7.8	0.52		3.32	10.3	0.096	10.3	0.096	0.0093
688	3.05	19.02	7.75	1.51		3.48	10.0	0.095	10.0	0.095	0.0095
842	2.81	19.03	7.85	0.51		3.80	10.1	0.096	10.7	0.096	0.0095
1100	2.46	19.07	7.9	0.63		3.70	10 2	0.100	10.2	0.100	0.0098

Oceanographycal Observation by "Oshoro-Maru"

Depth	Temp.	Cl	pH	O_2	Silicate	Phosphate	recalculated based upon Cl 19‰				
					Si	P	Ca	Sr	Ca	Sr	Sr/Ca
m	°C	‰		cc/L	μg-at	μg-at	mg-at	mg-at	mg-at	mg-at	
Station 30. Date: Aug. 5. Time: 1530-1610 Lat.: N 63°03.4′ Long.: W 172°54′											
0	9.7	17.68	8.4		4.6	0.56	9.9	0.089	10.6	0.096	0.0090
10	8.06	17.69	8.35		4.0	0.60	9.5	0.091	10.2	0.098	0.0096
25	4.28	17.68	8.4		4.4	0.49	9.9	0.094	10.6	0.101	0.0095
50	-1.39	17.99	7.65		32	2.38	9.7	0.094	10.2	0.099	0.0097
60	-1.62	17.99	7.65		32	1.96	10.0	0.095	10.5	0.100	0.0095
Station 33. Date: Aug. 6 Time: 1605-1620 Lat.: N 61°21′ Long.: W 168°58′											
0	8.1	17.36	8.1			0.60	9.5	0.072	10.3	0.080	0.0076
Station 44. Date: Aug. 13 Time: 2020-2125 Lat.: N 51°50′ Long.: W 172°00′											
0	10.6	17.89	8.3	6.82	8.2	0.60	10.0	0.086	10.6	0.092	0.0086
10	8.65	17.99	8.3	7.26	9.1	0.87	10.1	0.086	10.6	0.091	0.0085
25	4.75	18.21	8.0	5.74	31	1.95	10.1	0.074	10.5	0.078	0.0073
50	4.39	18.34	7.9	4.90	34	2.19	10.1	0.079	10.4	0.082	0.0078
70	4.32	18.41	7.9	4.53	45	2.41	9.9	0.079	10.2	0.082	0.0080
94	4.27	18.46	7.9	4.24	45	2.49	10.3	0.079	10.6	0.082	0.0077
141	4.30	18.51	7.9	3.98	49	2.54	10.2	0.090	10.5	0.093	0.0088
188	4.26	18.56	7.85	3.67	51	2,62	10.2	0.089	10.4	0.091	0.0087
259	4.31	18.60	7.8	3.23	53	2.66	10.2	0.083	10.2	0.085	0.0081
347	4.58	18.71	7.8	2.20	52	2.89	10.3	0.074	10.4	0.075	0.0072
431	4.31	18.78	7.7	1.77	58	3.04	9.9	0.074	10.0	0.075	0.0075
519	3.15	18.85	7.7	0.84	68	3.17	10.2	0.074	10.3	0.075	0.0073
698	3.72	18.92	7.6	0.58	75	3.31	10.2	0.091	10.2	0.091	0.0089
881	3.29	19.00	7.7	0.55	99	3.43	10.3	0.094	10.3	0.094	0.0091
1068	2.94	19.02	7.75	0.61	99	3.33	10.3	0.092	10.3	0.092	0.0089
1373	2.54	19.09	7.8	1.02	103	3.21	10.2	0.092	10.2	0.092	0.0090
Station 47. Date: Aug. 15 Time: 0300-0455 Lat.: N 48°13′ Long.: W 172°00′											
0	13.4	18.20	8.2	6.16	30	1.53	10.2	0.092	10.6	0.096	0.0090

Oceanographycal Observation by "Oshoro-Maru"

Depth	Temp.	Cl	pH	O_2	Silicate	Phosphate	recalculated based upon Cl ‰				
					Si	P	Ca	Sr	Ca	Sr	Sr/Ca
m	°C	‰		cc/L	µg-at/L	µg-at/L	mg-at/L	mg-at/L	mg-at/L	mg-at/L	
Station 48. Date; Aug. 16. Time: 0505-0615 Lat.: N 47°38.2' Long.: W 176°20.8'											
0	14.0	18.16	8.2	6.13	30	1.34	10.0	0.090	10.4	0.094	0.0090
10	14.21	18.16	8.2	6.12	28	1.39	10.0	0.083	10.4	0.087	0.0083
25	10.20	18.21	8.1	7.29	28	1.43	10.2	0.074	10.6	0.080	0.0075
50	6.43	18.32	8.1	6.99	30	1.79	10.0	0.074	10.3	0.077	0.0074
73	5.58	18.32	8.1	6.94	32	1.88	10.0	0.074	10.3	0.077	0.0074
98	5.25	18.34	8.1	6.86	32	1.90	9.8	0.086	10.1	0.089	0.0088
148	4.63	18.52	8.0	6.25	33	2.03	9.8	0.098	10.1	0.101	0.0100
197	3.66	18.62	7.9	6.14	46	2.40	10.0	0.092	10.2	0.094	0.0092
290	3.52	18.73	7.8	2.96	60	2.90	9.8	0.086	9.9	0.087	0.0088
387	3.52	18.80	7.8	1.85	69	2.96	9.8	0.086	9.9	0.087	0.0088
481	3.52	18.86	7.7	1.38	71	3.19	9.8	0.095	9.9	0.096	0.0097
580	3.42	18.90	7.6	0.93	86	3.13	10.1	0.096	10.2	0.097	0.0095
770	3.26	18.98	7.6	0.63	90	3.00	10.1	0.095	10.1	0.095	0.0094
969	2.92	19.04	7.6	0.71	98	3.13	10.1	0.095	10.1	0.095	0.0094
1167	2.58	19.07	7.7	0.73	106	3.14	10.4	0.091	10.4	0.091	0.0087
1462	2.31	19.09	7.7	1.07	112	3.17	10.4	0.095	10.4	0.095	0.0091
Station 50. Date: Aug. 17 Time: 2115-2210 Lat.: N 46°07' Long.: E 175°35'											
0	19.4	17.98	8.2	7.09	30	1.19	9.8	0.089	10.3	0.094	0.0091
Station 52. Date: Aug. 20 Time: 0805-0815 Lat.: N 43°19.4' Long.: E 165°38.6'											
0	18.4	17.20	8.3		17	0.44	9.9	0.100	10.8	0.109	0.0101
Station 54. Date: Aug. 22. Time: 0805-0810 Lat.: N 43°06' Long.: E 155°49'											
0	19.4	18.52	8.3		3.3	0.17	10.0	0.110	10.2	0.112	0.0110
Station 55. Date: Aug. 23. Time: 0750-0900 Lat.: N 43°06' Long.: E 150°27'											
0	16.4	17.94	8.3		9	0.82	9.9	0.100	10.4	0.105	0.0101
Station 56. Date: Aug. 23. Time : 1805-1815 Lat.: N 43°06' Long.: 148°25'											
0	16.5	18.02	8.3		13	2.06	9.9	0.100	10.4	0.105	0.0101

Oceanographical Observation by "Umitaka-Maru"

Depth	Temp.	Cl	pH	O_2	Silicate	Phosphate	recalculated based upon Cl ‰				
					Si	P	Ca	Sr	Ca	Sr	Sr/Ca
m	°C	‰		cc/L	µg-at/L	µg-at/L	mg-at/L	mg-at/L	mg-at/L	mg-at/L	
Station 3. Date: Sept. 14. Time: 0533-0521 Lat. N34°55' Long. E 160°02'											
0	25.6	19.04		4.76		0.10	10.1	0.091	10.1	0.091	0.0090
Station 7. Date: Sept. 15. Time: 1122-1302 Lat.: N 35°02' Long. : E 165°28'											
0	25.4	19.05		4.69		0.10	10.0	0. 091	10.0	0.091	0.0091
Station 12. Date: Sept. 17. Time:0803-0853 Lat.: N 35°03' Long.: E 171°38'											
0	25.5	19.09		4.82		0.00	9.9	0.091	9.9	0.091	0.0092
Station 15. Date: Sept. 15. Time: 1826-2058 Lat.: N 35°04' Long.: E 174°42'											
0	25.4	19.04		4.86		0.10	10.3	0.091	10.2	0.091	0.0089
Station 21. Date: Sept. 21. Time: 0207-0410 Lat.: N 35°01' Long.: W 177°54'											
0	23.9	18.99		4.97		0.20	10.0	0.091	10.0	0.091	0.0091
10	23.94	18.99		4.94		0.25	10.2	0.087	10.2	0.087	0.0085
25	23.80	18.98		4.97		0.10	10.0	0.086	10.0	0.086	0.0086
49	18.55	19.10		6.19		0.20	9.9	0.083	9.9	0.083	0.0083
74	15.25	19.10		6.04		0.25	10.0	0.083	10.0	0.083	0.0083
98	14.44	19.08		5.37		0.60	10.0	0.086	10.0	0.086	0.0086
147	13.45	19.00		5.28		0.60	10.0	0.094	10.0	0.094	0.0094
196	12.70	19.02		5.22		0.70	10.0	0.094	10.0	0.094	0.0094
278	11.33	18.98		4.93		0.70	10.0	0.092	10.0	0.092	0.0092
371	10.07	18.92		4.92		1.05	10.1	0.095	10.1	0.095	0.0094
441	9.05	18.87		4.97		1.00	10.3	0.095	10.3	0.095	0.0092
530	7.20	18.79		4.29		1.50	10.3	0.095	10.3	0.095	0.0092
706	5.12	18.81		2.22		2.60	10.2	0.091	10.2	0.091	0.0089
883		18.92		0.98		2.60	10.2	0.094	10.2	0.094	0.0092
1324	2.89	19.02		0.54		2.70	10.2	0.092	10.2	0.092	0.0091
1766	2.31	19.10		0.67		2.60	10.1	0.092	10.1	0.092	0.0091
2207	1.89	19.14		1.47		2.60	10.0	0.092	10.0	0.092	0.0092

Oceanographical Observation by "Umitaka-Maru"

Depth	Temp.	Cl	pH	O_2	Silicate Si	Phosphate P	recalculated based upon Cl ‰ Ca	Sr	Ca	Sr	Sr/Ca
m	°C	‰		cc/L		μg-at/L	mg-at/L	mg-at/L	mg-at/L	mg-at/L	
Station 27. Date: Sept. 25. Time: 1728-1854 Lat.: N 27°10' Long.: W 166°15.0'											
0	25.8	19.62		4.18		0.15	10.0	0.095	9.7	0.092	0.0095
Station 36. Date: Oct. 12. Time: 0228-0433 Lat.: N 19°57' Long.: E 177°20'											
0	27.3	19.28		4.65		0.20	9.5	0.089	9.8	0.088	0.0090
Station 42. Date: Oct. 13. Time: 1829-2034 Lat.: N 20°01' Long.: E 170°50'											
0	27.6	19.35		4.53		0.25	10.3	0.091	10.1	0.089	0.0088
Station 45. Date: Oct. 14. Time: 1845-2100 Lat.: N 20°04' Long.: E 166°22'											
0	27.4	19.28		4.58		0.60	9.9	0.089	9.8	0.088	0.0090
Station 48. Date: Oct. 16. Time: 0148-0248 Lat.: N 20°20' Long.: E 163°03'											
0	28.5	19.40		4.58		0.15	9.9	0.089	9.7	0.087	0.0090
Station 51. Date: Oct. 17. Time: 0325-0523 Lat.: N 19°58' Long.: E 159°26'											
0	28.4	19.45		4.51		0.00	9.8	0.089	9.6	0.087	0.0091
Station 54. Date: Oct. 18. Time: 0341-0456 Lat.: N 19°47' Long.: E 155°25'											
0	28.7	19.26		4.45		0.10	9.9	0.089	9.8	0.088	0.0098
Station 57. Date: Oct. 19 Time: 0405-0625 Lat.: N 20°03' Long.: E 150°15'											
0	28.9	19.19		4.54		0.10	9.9	0.087	9.9	0.087	0.0088

Oceanographical Observation by "Umitaka-Maru"

Depth	Temp.	Cl	pH	O_2	Silicate Si	Phosphate P	recalculated based upon Cl 19‰ Ca	Sr	Ca	Sr	Sr/Ca
m	°C	‰		cc/L		μg-at/L	mg-at/L	mg-at/L	mg-at/L	mg-at/L	
Station 59. Date: Oct. 19. Time: 2005-2233 Lat.: N 20°00' Long.: E 148°00'											
0	28.5	19.17		4.54		0.10	9.8	0.090	9.8	0.090	0.0092
10	28.55	19.17		4.50		0.40	10.0	0.092	10.0	0.092	0.0092
25	28.59	19.18		4.49		0.10	10.1	0.095	10.1	0.095	0.0094
49	28.65	19.26		4.56		0.10	10.1	0.094	10.0	0.093	0.0093
74	28.33	19.31		4.60		0.10	10.0	0.090	9.9	0.089	0.0090
98	26.57	19.40		4.78		0.15	10.0	0.095	9.8	0.093	0.0095
148	22.60	19.45		4.54		0.15	10.0	0.092	9.8	0.090	0.0092
190	20.55	19.42		4.25		0.35	10.1	0.091	9.9	0.089	0.0090
285	19.22	19.42		4.25		0.35	10.0	0.088	9.8	0.087	0.0088
387	13.28	19.06		4.29		0.80	10.0	0.088	10.0	0.088	0.0088
487	9.77	18.92		3.56		1.20	10.1	0.089	10.1	0.089	0.0088
580	7.46	18.92		2.67		2.10	10.2	0.090	10.2	0.090	0.0088
774	5.36	19.18		2.15		1.30	10.2	0.091	10.2	0.091	0.0089
967	4.15	19.06		1.45		2.50	10.2	0.091	10.2	0.091	0.0089
1457	2.77	19.14		2.00		2.60	10.3	0.092	10.3	0.092	0.0089
1946	2.18	19.16		2.53		2.60	10.2	0.090	10.2	0.090	0.0088
2436	1.81	19.18		2.51		2.60	10.4	0.092	10.4	0.092	0.0089

Oceanographical Observation by "Satsuma".

Depth	Temp.	Cl	pH	O_2	Silicate	Phosphate	recalculated based upon Cl 19‰				
					Si	P	Ca	Sr	Ca	Sr	Sr-Ca
m	°C	‰		ml/L	μg-at/L	μg-at/L	mg-at/L	mg-at/L	mg-at/L	mg-at/L	
St. Sa. 3. Date: July 31 Time: 1300-1510 Lat. N 17°00' Long. E 151°00'											
0	29.2	19.35	8.4	4.52	0.0	0.00	10.0	0.092	9.8	0.090	0.0092
10	28.89	19.31	8.4	4.49	0.0	0.00	10.3	0.100	10.1	0.098	0.0097
25	28.84	19.30	8.4	4.20	0.0	0.00	10.3	0.100	10.1	0.098	0.0097
49	26.89	19.50	8.4	4.99	0.0	0.00	10.4	0.100	10.1	0.097	0.0096
104	24.39	19.55	8.4	4.60	0.0	0.00	10.5	0.099	10.1	0.095	0.0094
154	22.03	19.49	8.3	4.18	0.0	0.37	10.3	0.096	10.0	0.093	0.0093
203	18.86	19.36	8.3	4.51	20.5	0.59	10.4	0.099	10.2	0.097	0.0095
303	13.96	19.15	8.1	4.36	20.0	0.87	10.2	0.100	10.1	0.099	0.0098
403	10.32	18.94	8.1	3.65	27.5	1.56	10.0	0.094	10.0	0.094	0.0094
533	6.38	18.9	7.8	1.94	58.0	2.16	10.2	0.094	10.2	0.094	0.0092
651	5.85	19.03	7.8	1.57	58.0	2.22	10.2	0.095	10.2	0.095	0.0093
828	4.91	19.07	7.8	1.51	72.0	2.31	10.3	0.097	10.3	0.097	0.0094
1027	3.92	19.12	7.8	1.84	75.0	2.46	10.3	0.099	10.2	0.098	0.0096
St. Sa. 7. Date: Aug. 2 Time: 0810-1545 Lat. N 10°56' Long. E 150°57'											
0	28.8	18.99	8.4	4.78	0.0	0.00	10.3	0.087	10.3	0.087	0.0085
10	28.33	18.99	8.4	4.88	0.0	0.00	10.2	0.098	10.2	0.098	0.0096
25	28.35	18.99	8.4	4.85	0.0	0.00	10.2	0.098	10.2	0.098	0.0096
50	28.34	19.00	8.4	4.81	0.0	0.00	10.2	0.100	10.2	0.100	0.0098
100	26.20	19.35	8.4	4.73	0.0	0.00	10.7	0.106	10.5	0.104	0.0099
150	20.64	19.33	8.3	4.13	0.0	0.51	10.7	0.104	10.5	0.102	0.0097
212	12.58	19.03	8.1	3.97	16.5	1.20	10.3	0.104	10.3	0.104	0.0101
310	8.68	19.01	7.8	1.82	28.5	2.25	10.5	0.090	10.5	0.090	0.0086
407	7.43	19.07	7.8	1.53	36.0	2.46	10.5	0.092	10.5	0.092	0.0088
505	6.74	19.10	7.8	1.70	44.0	2.52	10.6	0.099	10.5	0.098	0.0093
615	5.93	19.10	7.8	1.75	58.0	2.61	10.6	0.107	10.5	0.106	0.0101
810	9.00	19.10	7.8	1.65	64.0	3.36	10.5	0.099	10.4	0.098	0.0094
1005	4.22	19.15	7.8	1.53	72.0	3.84	10.5	0.099	10.4	0.098	0.0094

Oceanographical Observation by "Satsuma"

Depth	Temp.	Cl	pH	O_2	Silicate	Phosphate	recalculated based upon Cl 19‰				
					Si	P	Ca	Sr	Ca	Sr	Sr/Ca
m	°C	‰		ml/L	μg-at/L	μg-at/L	mg-at/L	mg-at/L	mg-at/L	mg-at/L	
St. Sa. 10. Date: Aug. 4. Time: 0635-0925 Lat. N 06°27' Long. E 150°46'											
0	28.9	18.78	8.4	4.47	0.0	0.00	10.1	0.092	10.2	0.093	0.0091
9	29.17	18.80	8.4	4.41	0.0	0.00	10.1	0.096	10.2	0.097	0.0095
25	29.32	18.86	8.4	4.45	0.0	0.00	10.3	0.098	10.4	0.099	0.0095
50	28.41	19.11	8.4	4.50	0.0	0.00	10.3	0.096	10.2	0.095	0.0093
100	25.19	19.30	8.3	3.68	0.0	0.44	10.3	0.100	10.3	0.100	0.0097
150	15.71	19.17	8.1	3.06	17.5	0.81	10.4	0.096	10.3	0.095	0.0093
200	11.77	19.13	8.0	2.02	23.0	1.56	—	—	—	—	—
300	8.89	19.14	7.9	1.55	25.0	2.31	10.3	0.097	10.2	0.096	0.0094
400	8.12	19.13	7.9	1.97	30.5	2.31	10.3	0.096	10.2	0.095	0.0093
500	7.47	19.12	7.9	1.80	30.5	2.31	10.3	0.103	10.2	0.102	0.0100
600	6.80	19.11	8.1	1.79	32.0	2.55	10.3	0.096	10.2	0.095	0.0093
800	5.38	19.12	7.9	1.72	50.0	2.58	10.3	0.100	10.2	0.099	0.0097
1000	4.37	19.13	7.9	1.77	56.0	3.30	10.5	0.098	10.4	0.097	0.0093
St. Sa. 16. Date: Aug. 7. Time: 1030-1422 Lat. N 02°13' Long. E 150°00'											
0	29.2	19.06	8.4	4.65	0.0	0.00	10.5	0.097	10.5	0.097	0.0092
10	29.10	19.11	8.4	4.57	0.0	0.00	10.6	0.091	10.5	0.090	0.0086
25	29.16	19.14	8.4	4.54	0.0	0.00	10.5	0.098	10.4	0.088	0.0085
50	29.36	19.24	8.4	4.58	0.0	0.00	10.6	0.094	10.5	0.093	0.0089
100	27.72	19.50	8.3	3.96	0.0	0.42	10.7	0.095	10.4	0.092	0.0089
150	23.48	19.46	8.2	3.32	0.0	0.60	10.7	0.091	10.4	0.088	0.0085
205	13.04	19.14	8.1	2.64	15.5	1.50	10.5	0.091	10.4	0.090	0.0087
300	9.27	19.19	8.0	2.97	19.0	1.92	10.6	0.094	10.5	0.093	0.0089
396	8.80	19.17	7.9	2.86	24.0	1.98	10.7	0.086	10.6	0.085	0.0080
494	8.23	19.15	7.9	2.71	27.5	2.13	10.5	0.089	10.4	0.088	0.0085
551	7.67	19.14	7.9	2.94	27.0	2.13	10.5	0.091	10.4	0.090	0.0087
737	3.94	19.10	7.9	2.19	29.0	2.76	10.4	0.091	10.3	0.090	0.0088
930	4.61	19.11	7.9	2.06	33.5	2.81	10.3	0.095	10.2	0.094	0.0092

Oceanographical Observation by "Satsuma"

Depth	Temp.	Cl	pH	O_2	Silicate	Phosphate	recalculated based upon Cl 19‰				
					Si	P	Ca	Sr	Ca	Sr	Sr/Ca
m	°C	‰		ml/L	μg-at/L	μg-at/L	mg-at/L	mg-at/L	mg-at/L	mg-at/L	
St. Sa. 17. Date: Aug. 7 Time: 2340-0255 Lat. N 03°29' Long. E 149°05'											
0	28.6	18.83	8.4	4.57	0.0	0.00	10.0	0.099	10.1	0.100	0.0099
10	28.78	18.81	8.4	4.61	0.0	0.00	10.0	0.094	10.1	0.095	0.0094
24	28.79	18.81	8.4	4.57	0.0	0.00	10.2	0.094	10.3	0.095	0.0092
48	28.73	19.00	8.4	4.68	0.0	0.00	10.4	0.104	10.4	0.104	0.0100
97	26.68	19.20	8.4	4.39	0.0	0.00	10.2	0.099	10.1	0.098	0.0097
146	22.88	19.33	8.3	—	0.0	0.45	10.3	0.097	10.1	0.096	0.0094
179	18.73	19.25	8.2	3.27	12.0	0.96	10.1	0.099	10.0	0.098	0.0098
330	8.24	19.16	7.9	2.07	26.0	2.34	10.1	0.099	10.0	0.098	0.0098
410	7.79	19.16	7.8	2.39	31.5	2.22	10.5	0.103	10.4	0.102	0.0098
492	7.25	19.13	7.8	2.47	44.0	2.16	10.3	0.106	10.2	0.105	0.0103
535	6.99	19.13	7.9	2.60	43.0	2.22	10.5	0.100	10.4	0.099	0.0095
708	5.19	19.11	7.9	2.10	51.0	2.61	10.3	0.101	10.2	0.100	0.0098
889	4.71	19.11	7.8	2.07	62.0	2.72	10.4	0.103	10.3	0.102	0.0097
St. Sa. 29. Date: Aug. 16. Time: 2230-0120 Lat. N 03°38' Long. E 141°56'											
0	28.5	19.00	8.4	4.56	0.0	0.00	10.0	0.090	10.0	0.090	0.0090
10	28.82	19.16	8.4	4.52	0.0	0.00	9.9	0.096	9.8	0.095	0.0097
25	28.83	19.17	8.4	4.64	0.0	0.00	10.2	0.094	10.1	0.093	0.0092
50	28.85	19.18	8.4	4.55	0.0	0.00	10.3	0.099	10.2	0.098	0.0096
100	27.64	19.49	8.3	3.86	0.0	0.50	10.5	0.097	10.3	0.095	0.0092
147	22.16	19.30	8.3	3.64	0.0	0.69	10.0	0.097	9.9	0.096	0.0097
181	17.20	19.22	8.1	3.40	13.0	1.10	10.2	0.098	10.1	0.097	0.0096
268	9.78	19.15	7.8	1.58	20.0	2.40	10.2	0.100	10.1	0.099	0.0098
356	8.66	19.15	7.9	2.80	20.0	2.40	—	—	—	—	—
444	8.11	19.15	7.9	3.05	23.0	2.52	10.3	0.096	10.2	0.095	0.0093
527	7.56	19.14	7.8	1.80	26.5	3.04	10.2	0.094	10.1	0.093	0.0092
698	6.16	19.11	7.8	1.87	31.5	3.08	10.2	0.094	10.1	0.093	0.0092
868	5.03	19.11	7.8	1.92	54.0	3.40	10.2	0.094	10.1	0.093	0.0092

Oceanographical Observation by "Satsuma"

Depth	Temp.	Cl	pH	O_2	Silicate	Phosphate	recalculated based upon Cl 19‰				
					Si	P	Ca	Sr	Ca	Sr	Sr/Ca
m	°C	‰		ml/L	μg-at/L	μg-at/L	mg-at/L	mg-at/L	mg-at/L	mg-at/L	
St. Sa. 31. Date: Aug. 18. Time: 0630-1150 Lat. S 01°04' Long. E 140°02'											
0	28.8	19.31	8.4	4.55	0.0	0.00	10.2	0.094	10.0	0.092	0.0092
10	29.06	19.22	8.4	4.56	0.0	0.00	—	—	—	—	—
25	29.08	19.13	8.4	4.55	0.0	0.00	—	—	—	—	—
50	29.14	19.32	8.4	4.54	0.0	0.00	—	—	—	—	—
100	28.85	19.47	8.4	4.33	0.0	0.32	10.4	0.100	10.2	0.098	0.0096
150	24.07	19.65	8.3	3.21	0.0	0.74	—	—	—	—	—
219	18.99	19.62	8.2	3.19	0.0	1.44	10.4	0.095	10.1	0.092	0.0091
318	12.19	19.34	8.1	3.57	10.5	1.68	10.2	0.092	9.9	0.089	0.0090
417	8.65	19.19	8.0	3.28	17.0	2.16	10.4	0.094	10.2	0.092	0.0090
516	7.71	19.13	8.0	3.34	22.0	2.31	10.2	0.098	10.1	0.097	0.0096
615	6.33	19.10	8.0	3.49	26.0	2.46	10.3	0.094	10.2	0.093	0.0091
812	5.06	19.11	7.8	2.72	38.5	3.20	10.3	0.098	10.2	0.097	0.0095
1010	4.34	19.11	7.8	2.37	64.0	3.00	10.3	0.092	10.2	0.091	0.0089
1208	3.64	19.12	7.8	2.57	70.0	2.96	10.3	0.092	10.2	0.091	0.0089
1495	2.95	19.13	7.8	2.60	100.0	2.72	10.4	0.092	10.3	0.091	0.0088
1990	2.28	19.16	7.8	2.69	104.0	2.52	10.4	0.094	10.3	0.093	0.0090
2539	1.78	19.17	7.9	3.03	110.0	2.88	10.4	0.092	10.3	0.091	0.0088

Depth	Temp.	Cl	pH	O_2	Ca	Sr	recalculated based upon Cl 19‰ Ca	Sr	Sr/Ca
m	C	‰			mg-at	mg-at	mg-at	mg-at	
Station 13 Date : Nov. 10. Lat.: 15°05.0′ Long E 125°06.0′									
0	28.75	18.98	8.3	4.18	9.9	0.098	9.9	0.098	0.0099
Station 15 Date: Nov. 11. Lat.: N 12°00.0′ Long E 126°00.0′									
0	28.95	19.09	8.35	4.36	10.2	0.098	10.2	0.098	0.0096
Station 17 Date : Nov. 12. Lat.: N 08°30.0′ Long E 127°18.0′									
0	28.90	18.98	8.3	4.38	10.2	0.094	10.2	0.094	0.0092
Station 20 Date: Nov. 13. Lat.: N 04°14.0′ Long E 128°55.0′									
0	29.14	19.26	8.35	4.35	10.1	0.104	10.0	0.103	0.0103
Station 1-3 Date: Nov. 30. Lat.: S 09°54.0′ Long E 91°59.0′									
0	28.1	19.13	8.3	4.58	10.5	0.094	10.4	0.093	0.0089
Station 1-6 Date: Dec. 3. Lat.: S 12°48.0′ Long E 78°03.8′									
0	26.8	19.19	8.3	4.67	10.2	0.104	10.1	0.103	0.0102
Station 1-9 Date: Dec. 6. Lat.: S 15°11.0′ Long E 64°34.5′									
0	26.7	19.47	8.25	4.77	10.5	0.098	10.3	0.096	0.0091
Station 1-18 Date: Dec. 15 Lat.: S 29°00.5′ Long E 39°03.0′									
0	23.1	19.52	8.3	5.07	10.5	0.105	10.2	0.103	0.0100
Station 1-23 Date: Mar. 26 Lat.: S 06°05.0′ Long E 73°11.0′									
0	29.3	19.11	8.3	4.51	10.1	0.105	10.0	0.104	0.0104

"Umitaka-maru" - Antarctic Cruise, October, 1956 - April, 1957.

Depth	Temp.	Cl	pH	O_2	Ca	Sr	recalculated based upon Cl 19‰ Ca	Sr	Sr/Ca
m	C	‰			mg-at/L	mg-at/L	mg-at/L	mg-at/L	
Station A-6 Date: Jan. 7. Lat: S 65°040′ Long E 52°49.5′									
0	-0.13	18.81	8.0	8.12	10.1	0.105	10.2	0.106	0.0104
Station A-10 Date: Jan.11. Lat.: S 67°08.0′ Long E 38°37.4′									
0	-0.78	18.34	8.0	8.18	10.0	0.105	10.3	0.108	0.0105
Station A-16 Date: Jan. 15. Lat.: S 68°52.5′ Long E 25°33.5′									
0	-0.25	18.30	8.15	8.97	10.0	0.100	10.4	0.104	0.0100
Station A-43 Date: Feb. 9. Lat.: S 68°12.0′ Long E 23°31.0′									
0	0.76	18.63	8.1	8.32	10.1	0.100	10.3	0.102	0.0099
Station A-49 Date: Mar. 3. Lat.:S 59°10.5′ Long E 27°05.0′									
0	1.53	18.69	8.1	7.30	10.1	0.100	10.3	0.102	0.0099
Station A-55 Date: Mar. 8. Lat: S 39°00.0′ Long E 20°26.0′									
0	21.23	19.65	8.3	5.06	10.5	0.104	10.2	0.101	0.0099